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EPISTEMIC ASPECTS OF ENGINEERING FOR K-12 EDUCATION

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Abstract

Epistemic Aspects of Engineering for K-12 Education

by
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The recent science education standards placed a special emphasis on engineering design to build a foundation of students' learning in engineering and enhance their scientific understanding by using engineering as a real-world context. However, the standards documents put a strong focus on engineering design without providing a comprehensive outlook on the features of the engineering discipline. Such an approach could deprive students of the chance to develop disciplinary knowledge and understand the connections between engineering, science, technology, and society. In this respect, the aim of this study was to illuminate the epistemic aspects of engineering for K-12 science and engineering education. In this study, a mixed methodology which incorporates constructivist and pragmatic paradigms was performed. A three-round Delphi study was conducted with an expert panel including practicing engineers in industry, researchers in the field of philosophy/history of engineering, and engineering/science educators. The themes, drawn from the Delphi study, were further analyzed and discussed with the experts in the field of K-12 science and engineering education. The constructivist grounded theory was employed in order to analyze the data. The study unraveled twenty-three themes coupled with twelve overarching themes with respect to the epistemic aspects of engineering. The conceptual framework which sheds light on the epistemic aspects of engineering could be invaluable for teacher preparation, professional development programs, and for those who are

concerned with enhancing their daily classroom practices as well as K-12 curriculum developers and policymakers.

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Last but not least, I have to express my gratitude to stars. If you were not kind enough to explode and died in supernova explosions, I would not be here today and write my dissertation.

Dedication

Dedicated to my devoted parents, Nurten Yesilyurt and Kemal Yesilyurt who were with me every step of the way. Without your support and encouragement, this work would not have been possible.

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Chapter 1

Introduction

Since the Next Generation Science Standards [NGSS] (2013) placed a strong emphasis on including engineering in K-12 science education, there is a growing interest in engineering education in K-12 settings. The arguments for the inclusion of engineering design in K-12 science education include the application of science and mathematics knowledge to problem-solving tasks, creating interest in Science, Technology, Engineering, and Mathematics [STEM] careers, fostering technological literacy, and supporting 21st-century skills (NGSS Lead States, 2013).

The inclusion of engineering design could provide students with a unique opportunity to develop an idea and learn disciplinary practices (Wendell & Kolodner, 2014). Such an approach necessitates the epistemic focus, and an attempt to conceptualize how knowledge is constructed in a discipline (Sandoval, 2003). The epistemic aspects of engineering which illuminate what counts as engineering knowledge, what practices that engineers engage in to solve problems, and what values, norms, and rules that the engineering community have. Even though the NGSS integrates the engineering design as a set of core ideas and practices in science education for the first time in the U.S., the standards do not sufficiently address the concepts and features of engineering (e.g., Cunningham & Carlsen, 2014; Antink-Meyer & Brown, 2019). In this case, students are expected to focus solely on solving engineering design problems without reflecting upon the epistemic aspects of the overall engineering design process.

This begs the question of whether engaging students in design practices alone help students develop disciplinary knowledge. In that regard, the research in science education could guide us in framing engineering for K-12 education. The research on the nature of science and scientific inquiry yielded empirical evidence indicating that instructional designs that engage students in particular practices are not sufficient to build foundational conceptual knowledge with regard to the nature of the discipline (Bell et al., 2003; Sandoval & Morrison, 2003). Thus, exposing students with engineering design experiences alone will not provide the necessary conceptual foundation that students need to further build conceptions upon and consolidate them. Only when students were explicitly introduced to the concepts related to the nature of the discipline and given opportunities to reflect their own experiences, they can develop a deep understanding of the epistemology of the discipline. From this perspective, integrating design practices in science education contexts with no emphasis on the core features of the engineering discipline not only would deprive students of an opportunity to learn a new discipline but also promote misunderstandings.

A recent study unraveled that the current status of engineering education in the U.S. (Moore et al., 2015). Most states still introduce engineering as a technological design or as a part of the nature of technology, let alone address the epistemic aspects of engineering even after the release of the NGSS. Given the fact that teachers do not receive sufficient and formal training with respect to engineering (Lederman& Lederman, 2014), this new vision of science teaching and learning apparently poses a challenge for educators. Therefore, the full range of epistemic aspects of engineering should be identified and integrated to realize the full potential of engineering education.

The Place of Engineering Education in the Science Standards

The place of engineering practices within the context of science education is mainly conceived as complementary experiences for science concepts and practices (National Research Council [NRC], 2012; Bybee, 2014). Engineering provides a real-world context within which students can make sense of their knowledge about the natural world to enhance their scientific understanding. It was also underlined that by using engineering and technology as a context, students could appreciate the interrelationships among four disciplines and understand the interdisciplinary nature of STEM.

On the other hand, the Framework also portrays engineering as a distinct discipline throughout the document. Similarly, the documents related to the NGSS claimed that the inclusion of engineering in science education serves another purpose which centers on the aim to introduce engineering as an important and distinct discipline with its unique and shared features (NRC, 2014). However, conceptualizing engineering within the discipline of science has risks that deepen students' existing misconceptions concerning engineering. Further, several statements made in the documents frame engineering as a mere practical use of science. Although engineering exploits knowledge about the natural world, the philosophy of engineering reveals that engineering is much more than the application of science. The Framework made an attempt to identify the differences between science and engineering disciplines and suggest the aim and the end product as two primary characteristics that distinguish between engineering and science. Nevertheless, this simplistic view will deprive students of understanding engineering as a different way of knowing and doing as well as a discipline with its own values, standards, and norms. Therefore, the distinction between science and engineering should be clearly addressed, developing a broader outlook that presents engineering as a distinct discipline that has its own body of knowledge, methods, norms, values, and epistemic commitments.

The Research on the Nature of Engineering in K-12 Settings

The growing focus on the integration of engineering education to science education standards originated from efforts initiated in the early 2000s in order to spark students' interest in and promote knowledge base necessary pursue STEM fields (e.g., Brophy et al., 2008; Moore et al., 2015; Purzer & Shelley, 2018). Those efforts contributed to the recognition of engineering as an important discipline that has the potential to offer a real-life context in which students can make sense of their understanding of scientific and mathematical principles. On the other hand, several scholars and policy-based studies acknowledged engineering as an important discipline in and of itself. They advocated the integration of engineering into science education standards as a relevant but distinct discipline (e.g., Brophy et al., 2008; Cunningham & Kelly, 2017; NRC, 2010).

Since the release of the NGSS, numerous concerns have been raised with respect to the framing of engineering in the standards (Cunningham & Carlsen, 2014; Mccomas & Nouri, 2016; Wendell & Kolodner (2014). Cunningham and Carlsen (2014), for instance, cautioned against the distinction between science and engineering disciplines that Framework portrays. The scholars discussed that such conceptualization of two disciplines could potentially create or cause further misunderstandings about engineering as being an applied to science. Even though the NGSS focuses mainly on the engineering design as a central concept of engineering, several scholars have argued that the science standard documents do not adequately reflect the full range of engineering ideas required to conceptualize engineering as a distinct discipline with its own unique characteristics (Antink-Meyer & Brown, 2019; Pleasants & Olson, 2018). Another concern has been raised regarding overemphasis on technical competencies and thus, less attention is given to the care and moral dimensions of engineering in the standard documents (Gunckel & Tolbert, 2018).

Many scholars considered that the integration of engineering in the pre-college science education could be a great opportunity to develop a disciplinary knowledge as to the engineering discipline (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2014; Deniz et al., 2019; Gunckel & Tolbert, 2018; Pleasants & Olson, 2019). For that reason, several scholars attempted to investigate the nature of engineering and practices in order to offer a more comprehensive outlook for engineering in the standards. While the research on the epistemic aspects of engineering and engineering practices is still at infancy, the research studies and previous policy-based studies seem to concur on the engineering design as a key aspect of engineering. On the other hand, the studies also unearth the key role of social practices in the engineering design (e.g., Deniz et al., 2019; Cunningham & Kelly, 2014).

Research on the Conceptions of K-12 Students and Teachers

The incorporation of engineering into the NGSS has prompted the research efforts on K-12 engineering education (Moore et al., 2015). While the discussions are currently underway regarding what constitutes as engineering and how it should be framed in science education, there seems a general consensus among scholars with respect to the benefits of incorporating engineering in the pre-college education as it has the potential to foster students' science and mathematics understandings and develop a disciplinary knowledge about engineering. In that respect, several scholars have turned their attention to elucidate the conceptions that students had about the nature of engineering. In this line of research, several studies explicated widely held students' perceptions and beliefs concerning engineering. It was reported that students' conceptions with regard to engineering were in stark contrast to the current views of engineering and show some similarities with the traditional views of engineering which posits that engineering is the practical end of natural sciences and thus, requires mere technical competence. It appears that this misconceived view of engineering still exists among pre-college students and teachers. Besides, they did not have a broader outlook on engineering and its practices, thereby missing important features of the discipline. By putting more emphasis on the technical aspects of engineers, they conceived engineering as the discipline typically concerned only with technical applications such as building, fixing, and repairing (e.g., Fralick et al., 2009; Karatas et al., 2011; Capobianco et al., 2011; Knight & Cunningham, 2004). From this perspective, students reduce engineers' roles in the creation process to those of technicians or workers. It seems that students not only held misconceptions, but they also lack knowledge with respect to conceptual, social, and contextual aspects of engineering that are essential to the design process.

After the release of the NGSS, concerns have been raised with respect to inadequate knowledge and experience that K-12 teachers held concerning engineering. Policy-based studies, for instance, drew the attention to the possible challenges that teachers might face in integrating engineering into the science programs (NRC, 2009, 2014). Several studies yielded empirical data that confirm these concerns (e.g., Wendell et al., 2019; Kilty & Burrows, 2019). To be more specific, studies revealed that teachers are not well equipped with the necessary knowledge, thereby having low confidence in integrating engineering in their teaching (Hammack & Ivey, 2017; Katehi et al., 2009; Moore, 2012; Trygstad et al., 2013). A significant number of teachers have little or no exposure to engineering and engineering teaching during their education (Banilower et al., 2018; Cunningham & Carlsen, 2014; Lederman & Lederman, 2013). They, thus, avoid teaching or integrating engineering in their science instructions (Kim & Oliver, 2018).

It seems that the low confidence in and experience with respect to engineering are not the only concerns about the preparedness of teachers in teaching engineering. Several studies unraveled inaccurate and inadequate views that teachers had about the nature of engineering and engineering activities (e.g., Honey et al., 2014; Lachapelle et al., 2006).

Even though the nature of engineering is still an emerging research area, studies clearly illustrated that the technical work is an integral part of the design process, engineering activities also requires social and conceptual competencies including, but not limited to, communication, synthesizing scientific knowledge, creativity, idea generation, etc. (e.g., Cunningham & Kelly, 2017; Deniz et al., 2019). However, it appears that the conceptions that teachers held about engineering are not what is considered adequate conceptions of the nature of engineering (Hsu et al., 2011; Lambert et al., 2007). Besides, it was unearthed that teachers held misconceptions about the NGSS engineering practices, which in turn, indeed had an influence on how teachers frame engineering activities and engage their students in those activities (Antink-Meyer & Meyer, 2016; Kang et al., 2018; Wendell et al., 2019). In this respect, a conceptual framework highlighting the epistemic aspects of engineering could not merely be beneficial for teachers to address the important and distinct features of engineering but also to create meaningful engineering design activities.

Philosophy of Engineering for K-12 Engineering Education

Although studies have started to uncover key practices and aspects of engineering discipline, we have still much to learn about its fundamental characteristics and practices. In that regard, this study took an epistemological approach to unearth the key aspects of engineering that could shed light on what engineering knowledge and its processes are and how those are different from the other forms of knowledge and practices for K-12 engineering education. Therefore, the aim here was to explore productive epistemologies of professional engineering for learning engineering. From this perspective, the main purpose of this study was to unravel views of professionals in the field of engineering concerning the characteristics and practices of professional engineering.

Besides, this study also exploited the philosophical and historical studies on engineering to examine the findings of the study in light of philosophical arguments. The philosophy of engineering has recently gained momentum that led to the proliferation of studies attempting to identify the epistemological aspects of engineering (e.g., Christensen et al., 2015; Dias, 2019; Gabbay et al., 2009; Michelfelder et al., 2014; Michelfelder et al., 2016; Sheppard et al., 2006; van de Poel & Goldberg, 2010). Sellars (1963) asserted that "philosophy aims to see how things, in the broadest possible sense, hang together in the broadest possible sense." (p. 1). In this respect, what engineers know, what practices they engage in, how they design, and what values, rules, and norms that they have are the main questions that the philosophy of engineering strives to find answers for. Those studies debunked the traditional view of engineering as a mere application of science knowledge (e.g., Christensen et al., 2015; Gabbay et al., 2009; Michelfelder et al., 2016). The studies indicated science and engineering are often hard to distinguish given that they are intimately intertwined with each other, but still, there are distinctive elements that need to be addressed. In a general sense, science is interested primarily in making sense of the natural world whereas engineering is concerned mainly with how the current situation can be modified rather than how things actually are. Such different purposes pointed out different epistemologies (e.g., Goldman, 2017; Vincenti, 2009).

Besides, philosophers and historians portrayed engineering as a social activity beyond traditional assumptions that centers solely on technical design aspects (e.g., Anderson et al., 2010; Bucciarelli, 1994; Voland, 2004).

Significance of the Study

Engineering decisions fundamentally change societal activities and relationships and redesign the world around us. On the other hand, people living in this designed world have little knowledge about how the design artifacts, systems, and processes that influence all facets of our lives are created (International Technology and Engineering Educators Association [ITEEA], 2020). Besides, the societal problems that people are facing have become increasingly more complex. To address those problems and make informed judgments about the use, benefits, and risks of engineered designs on society and environment, K-12 students should understand the essential features of engineering as a form of knowledge, method, and as well as a way to shape our material world. In line with that, a series of policy documents recently underscored the value of understanding the characteristics of engineering in order to promote engineering literacy in K-12 education (ITEEA, 2020; National Academies of Sciences, Engineering, Medicine [NASEM], 2020; NRC, 2014). Thus, establishing the epistemic aspects of engineering is deemed required to deepen our understanding of what counts as engineering literacy.

Since pre-college engineering education is an emerging but not yet an established research area, only a handful of research delved into what features of the engineering should be an integral part of engineering education (e.g., Antink-Meyer & Meyer, 2019; Cunningham & Kelly, 2017; Deniz et al., 2019; Pleasants & Olson, 2018). In this sense, there is not yet established consensus on the epistemic aspects of engineering relevant to K-12 education within the science-engineering education community. Therefore, our understanding of what characteristics pertain to the engineering discipline is still only beginning to be recognized. It is of my belief that teaching epistemic aspects of engineering has a place in K-12 science and engineering education to build a foundation for understanding the epistemology of engineering. To this date, there is no study, to the researcher's knowledge, including practicing engineers in industry and researchers in the area of the philosophy and history of engineering along with science and engineering educators in a Delphi study to ascertain the epistemic aspects of engineering for K-12 education. I firmly believe that this group of experts would provide new insights into the productive epistemologies of engineering. Considering the paucity of knowledge that most teachers and students currently hold about engineering (Angeli et al., 2016; Antink-Meyer &Meyer, 2016; Moore, 2012), identifying epistemic aspects of engineering is a necessary step for achieving expectations for engineering education.

Therefore, the study seeks to explore the following research questions:

1. What epistemic aspects of engineering are considered to be fundamental to the engineering discipline by practicing engineers, science and engineering educators, and researchers in the field of philosophy and history of engineering/technology?
2. What epistemic aspects of engineering are considered to be important for K-12 science education by science and engineering educators?

Hence, this current study employed the Delphi method in an attempt to seek input from experts in the field of engineering. The overarching aim of this Delphi study was to identify the important features that pertain to the engineering discipline. However, the purpose of the current study was not to contribute to the literature of the philosophy of engineering but rather to use epistemology as an analytical lens to unpack the epistemic aspects of engineering to be integrated into K-12 education. In that regard, to examine the appropriateness of the epistemic aspects of engineering emerged from the Delphi study as well as how to tailor them to the pre-college science and engineering education, the focus group meeting was conducted with K-12 science and engineering educators. The constructivist grounded theory methodology was performed to not merely identify themes concerning epistemic aspects of engineering but unravel overarching themes by investigating the relationships among the themes as well.

Chapter 2

Literature Review

This chapter comprised four main sections. The chapter begins with a review of the science education standards. In this section, the place of engineering in the four main science education reform reports were examined. In the second section, students' and teachers' conceptions concerning engineering revealed in the relevant literature were presented. In the third section, the results of the studies examining the nature of engineering for pre-college education were reviewed. In the last section, the epistemic aspects of engineering that emerged from the literature on the philosophy and history of engineering were presented.

The Review of the Recommendations and Standards for Engineering Education in the Major Science Education Reform Documents

In this section, the recommendations and standards for engineering education in the major science education reform documents were reviewed and compared to examine the place of engineering in the documents. In 1983, an influential report, A Nation at Risk, was released by the National Commission on Excellence in Education to point out America's declining economic position in the world and call for action to improve the U.S. education system in order to prepare more students for scientific and technical careers (Gardner, 1983). After the release of this report, the national standards movement was launched to improve education for all. Since then, four major K-12 science education reform reports were released:

(1) Science for All Americans (American Association for the Advancement of Science [AAAS], 1989)

(2) Benchmarks for Science Literacy (AAAS, 1993)

(3) National Science Education Standards (National Research Council [NRC], 1996)

(4) Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) and Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

Science for All Americans (AAAS, 1989)

The main aim of this report was to identify the goals for science education to make scientific literacy core competency for all students. The National Council on Science and Technology Education with the support of scientists and educators proposed recommendations with respect to what understanding, and habits of mind learners should have to be a scientifically literate member of society.

The report underscored the importance of understanding the inherent connections among science, mathematics, and technology for being scientifically literate. Likewise, the report proposed a set of learning outcomes including "being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations" (AAAS, 1989, pp. xvii ± xviii).

The report comprises twelve chapters which are summarized in four major categories: (a) the scientific endeavor, (b) scientific views of the world, (c) perspectives on science, and (d) scientific habits of mind. Although there is no specific chapter devoted to engineering in this report, the concept of engineering is addressed in the chapters of the *Nature of Science*, *Nature of Mathematics* and *Nature of Technology* to underline its relationship with these fields. In the *Nature of Science* chapter, there is just one statement addressing the practical use of scientific knowledge by specialists from different fields including engineers. However, there is no specific mention of engineering or the work of engineers in this chapter. In the *Nature of Mathematics* chapter, the application of mathematics in the engineering field is addressed to point out the relationship between mathematics and technology. Specifically, the contribution of mathematics more generally to engineering as in designing computer hardware and programming techniques is underlined to indicate the relationship between mathematics and computer technology. In the *Nature of Technology* chapter, considerable attention is given to engineering. The chapter comprises recommendations on the nature of technology and focuses on the ways of thinking technology. These ideas are categorized into three strands: *Technology and Science, Design and Systems, and Issues in Technology*.

In this chapter, engineering is defined as "the systematic application of scientific knowledge in developing and applying technology" (AAAS, 1989, p. 26). This statement could be confusing because it implies that engineering is applied science. But later in this chapter, the use of design strategies in engineering is mentioned. Specifically, engineers' work is defined as the use of scientific and technological knowledge, together with the design strategies to solve practical problems. However, the difference between engineering and applied science is not addressed. In the *Technology and Science* strand, engineering design is identified as a component of technology that combines scientific inquiry and mathematical modeling. However, the engineering design process and scientific inquiry are different kinds of methods. Also, instead of providing an explicit definition for the design process, it was broadly defined as "construing a problem and designing a solution for it" (AAAS, 1989, p. 27) and the two phases of the engineering design process are emphasized: devising a general approach and working on the technical details of the building of artifacts, systems or processes.

Besides, the similarities between the aspects of the nature of science and engineering are underlined in this strand. Those include the application of mathematics, the combination of logic and creativity, the desire to be original, the professional experts, and public responsibility. However, the report does not provide a detailed description of each aspect of the nature of engineering. Along with the similarities among the fields, the standards clearly address the interdependence of science, technology, and engineering, especially the interconnectedness between science and technology.

Also, there is an attempt to distinguish engineering from other disciplines by highlighting the practical aspect of engineering in this chapter. The differences in the purposes of the engineers and scientists and the end product of these two fields are included. The aspect of social and cultural embeddedness of engineering is addressed by pointing out the direct influence of engineering designs on society and the role of social and cultural values in engineering decisions. In the *Designs and Systems* strand, several aspects of the engineering design process are discussed. The importance of constraints in engineering design is emphasized by stating "the essence of engineering is design under constraint" (AAAS, 1989, p. 28). Six different types of constraints that engineers should consider when engaging in the design process are identified as physical laws, economic (money), social (convenience along with social-cultural values), political (regulations), ecological (its effects on the environment), and ethical factors (its effects on humans). The economic factors such as the costs of training personnel and testing engineering designs are regarded as the most important constraint in engineering design.

As for the role of creativity in engineering, the report presents an actual picture of engineering by stating that engineering sometimes involves routine decisions about the design but often creativity in inventing new solutions and/or technologies. Another aspect of engineering addressed in this section is the subjective nature of engineering design solutions. In particular, the report regards the making trade-off decisions as a critical component of the design process and addresses the possibility of the various solutions to a single problem.

Besides, the standards suggest the impact of human activities on our world, the knowledge of properties of materials, the concept of system and system models, the use of mathematics and computational thinking, and communication skills as the important aspects of the nature of technology in the *Designed World* and *Habits of Mind* chapters. However, there is no specific reference to engineering or engineers in these chapters.

All in all, *Science for All Americans* report addresses the engineering design constraints, the demarcation between science, mathematics and engineering, subjective, creative, and social-cultural aspects of engineering. However, these aspects are explained as aspects of the nature of technology. Although several phases of the engineering design process including the testing phase are emphasized, the standards fail to provide a complete picture of the engineering design process (engineering practices).

Benchmarks of Scientific Literacy (AAAS, 1993)

After four years, *Benchmarks of Scientific Literacy* was published as a companion report to *Science for All Americans*. SFAA describes the essential components of scientific literacy while Benchmarks outline the learning goals of SFAA in the form of learning expectations for each grade level span to suggest how students progressively achieve the skills and competencies to become scientifically literate. Specifically, the report includes recommendations for what K-12 students need to know and be able to do in science, mathematics, and technology by the end of several grade level spans, K-2, 3-5, 6-8, and 9-12. A team of teachers, university consultants, and scientists came together to develop the report.

The Benchmarks were updated in 2009, so there are current and 1993 versions of the report available on the AAAS website. Learning expectations in each chapter are organized around four grade spans: kindergarten through second grade (K-2) and grades three through five (3-5), grades six through eight (6-8), and grades nine through twelve (9-12).

In the *Nature of Technology* chapter, learning expectations related to engineering concepts are conceptualized around its association with technology. *Technology and Science* strand comprises only one benchmark for 6-8 and 9-12 grade students with respect to the engineering discipline. Specifically, the report suggests that students should have a broader view of technology and understanding of the difference between science and technology. In a similar vein, this benchmark expects middle and high school students to learn that engineers use scientific and technological knowledge while engaging in the design process to solve practical problems as well as how scientific knowledge is used by engineers to produce new technologies. Also, it is recommended that students learn about the different fields which involve science, technology, and engineering while starting to think about their own future careers.

In *Design and Systems* strand, the report suggests that the best way to learn the nature of engineering is to engage in design activities and projects. Therefore, this benchmark expects K-12 students to learn how to collect and analyze information, identify problems, formulate and assess creative ideas, use the ideas to produce solutions, and evaluate and improve solutions through participating in design processes. In contrast to SFAA, Benchmarks cover almost all phases of the engineering design process. Also, the report puts emphasis on the importance of having drawing and modeling skills and abilities to record the analyses in a problem-solving process. Another benchmark in this strand asks teachers to introduce the concept of design constraints and trade-offs in technology and students to take into consideration constraints and make trade-off decisions during the design process. The benchmark for 3-5 grade students aims to introduce the subjective nature of engineering design solutions. In particular, the benchmark states that upper elementary students should understand that there is no single best design but lots of solutions to a problem. This benchmark also stresses the importance of understanding the concept of failure- even good designs might fail. The benchmarks for 6-8 grade students include additional learning expectations including developing an understanding of the control mechanisms in complex systems and the side effects of engineering design on the environment and society. One of the benchmarks expects students to engage in inventing control mechanisms for their design. The other benchmark expects teachers to explicitly introduce physical, biological, economic, political, social, ethical, and aesthetic constraints to middle school students. The benchmarks for students in grades 9-12 aim to introduce new concepts such as risk analysis and technology assessment. However, these concepts are introduced as an aspect of the nature of technology because the role of engineers is not specified in the risk analysis and assessment of technologies. Lastly, there is also an implicit recommendation for the tentative nature of engineering. Specifically, it is suggested that learners should understand the value people place on any given technology can change through time.

In the *Issues in Technology* strand, there are several implicit recommendations related to engineers' work. Specifically, the standards put forward that "people" do invent new ways and approaches to solving problems, but it is not specified that it is the work of engineers. There are just two explicit recommendations with respect to engineering in this strand for middle and high school students. For 6-8 grade students, it is recommended that students should learn that "scientific laws, engineering principles, properties of materials, and construction techniques must be taken into account in designing engineering solutions to the problem" (AAAS, 1993, p. 55).

For 9-12 grade students, the benchmark suggests that students learn the requirement of secrecy in the engineering field as an aspect of individual ethics rather than professional ethics.

Overall, Benchmarks suggest student participation in engineering design activities and projects to provide them the opportunity to learn the design process. However, there is no explicit recommendation in this report concerning the teaching/learning of engineering concepts along with engaging in design activities.

The National Science Education Standards (NSES) (NRC, 1996)

The NSES proposed a comprehensive set of recommendations for the practice of K-12 science education. A group of teachers, parents, school administrators, science educators, scientists, engineers, and government officials contributed to the development of the standards. The NSES identify science content over the course of K-12 education and describe the exemplary practice of science teaching that helps K-12 students develop scientific literacy. The NSES address the key characteristics of quality science education programs and systems, and professional development programs for teachers. In the NSES, the grade spans are determined as K-4, 5-8, and 9-12. The NSES presents the science content standards in eight strands among which the *Science and Technology* strand includes the aspects of the nature of engineering.

In the *Science and Technology* strand, the NRC (1996) stated that “technology as the design is included in the standards as parallel to science as inquiry” (NRC, 1996, p. 24). This strand puts emphasis on the understanding of the design process and developing the ability to produce solutions to problems. However, the NSES state that the standards in this strand are not for technology education. Instead, these standards are formulated to develop students’ abilities related to the design process and help students understand the enterprise of science and its relation to technology. Like Benchmarks, the NSES also suggests engaging students in the design activities. For K-4 grade students, the standards address the desired abilities of technological design including (a) identify a simple engineering problem; (b) provide a solution; (c) implement solutions; (d) evaluating design solutions; (e) communicate the design solutions. Similar to the SFAA and Benchmarks, the NSES focus only on students' ability to design solutions through engaging in the design process rather than epistemic aspects of the engineering design process. In this strand, there is an implicit recommendation for the collaborative nature of engineering. Specifically, the standards expect K-4 grade students to understand scientists and engineers usually collaborate with different experts to contribute to the results. In the *Science in Personal and Social Perspectives* strand, the adverse and beneficial effects of inventions and designs on the environment and society are implicitly addressed. For 5-8 grade students, the standards suggest that students should be able to differentiate between science and technology by taking part in the design process. Engineering design activities are suggested to be used as complementary to scientific investigations to help students understand the science behind the designs and the differences between science and technology. Also, the subjective nature of engineering design -no single best design- along with the design constraints and trade-offs decisions are explicitly addressed in the standards.

For 9-12 grade students, the standards recommend that students engage in the problem-solving process to meet certain criteria while considering the design constraints. Namely, the standards expect students to understand the role of scientific ideas and methods in the design process and the importance of other sources of knowledge and skills including "cost, risk, and the benefit analysis, and aspects of critical thinking and creativity" in the design process (NRC, 1996, p. 191). In the standards, the principles of technological design do not change across grade levels but as they progress through grade levels, increasingly more sophisticated design problems and more sophisticated technological design principles are presented. Other learning expectations for high school students include developing an understanding of the interdependence between science and technology. Besides, the necessity of creativity, imagination, and having a good knowledge base is emphasized for the work of scientists and engineers. The standards also highlight the differences between scientific inquiry and "technological" design such that while the purpose of the scientific inquiry is to understand the natural world, the aim of the technological design is to solve human problems and meet human needs. Also, the direct effect of technological design on society is mentioned. Furthermore, the NSES provide exemplary ideas for design activities along with suggestions about how to implement them at each grade level.

To sum up, there is not much change in the *National Science Education Standards* in terms of the aspects of engineering. In the science and technology strand, the standards introduce the idea of the design process as for its relation to scientific investigation and technology. However, unlike the SFAA and Benchmarks, the NSES revised the concept of the design process by introducing additional steps such as implementing and communicating the design solutions and providing detailed explanations regarding the desired abilities of technological design. Also, the NSES clearly defines the purpose of the design process as solving human problems and meeting human needs. On the other hand, in all reports, the phases of the design process are introduced as technological design rather than the engineering design process. Additionally, teamwork, ethical aspects of engineering, and the subjective nature of engineering are implicitly emphasized. The social and cultural relatedness of engineering endeavors is explicitly mentioned. But this is apparently a limited view because engineering is addressed for its contribution to society but the influence of societal values and factors on engineering is not included in the standards.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012) /Next Generation Science Standards (2013)

Even though understanding of the designed world and the processes for building it have been considered as critical components of scientific literacy (AAAS, 1989; AAS, 1993; NRC, 1996), the inclusion of engineering into K-12 science education as a practice and as a domain of disciplinary knowledge is relatively recent. The current place of engineering K-12 standards grew from the early efforts to create more interest in STEM fields. In a highly influential report, Brophy et al. (2008) suggested the inclusion of engineering as a stand-alone discipline into K-12 curriculum programs. On the other hand, the NAE Standards Committee (2010) documented a number of challenges to this proposal including the shortage of teachers qualified to teach engineering, elementary and secondary schools' lack of emphasis on engineering education, and scarcity of instructional time devoted to engineering education. Therefore, the committee concluded that "although it is theoretically possible to develop standards for K–12 engineering education, it would be extremely difficult to ensure their usefulness and effective implementation" (NRC, 2010, p. 1). In this sense, instead of developing stand-alone engineering standards, the committee recommended two complementary approaches for engineering education: (1) infusion: embedding relevant learning goals from engineering to the existing science and mathematics standards and (2) mapping: integrating "big ideas" of engineering onto existing science and mathematics standards. In response, the NRC Committee included engineering as an important component of the science education in the Framework for K-12 Science Education (NRC, 2012) which was used as a basis to develop the NGSS.

The Next Generation Science Standards [NGSS] (2013) were released by the efforts of the National Research Council (NRC), the American Association for the Advancement of Science (AAAS) and National Science Teachers Association (NSTA). The new standards aim to merge knowledge and socially relevant applications. From this point of view, the NGSS integrates the engineering design process with science content to prepare students for the needs of 21st-century society. Compared to previous standards, the NGSS explicitly identifies engineering design and concepts as a foundational component of K-12 science education.

The *Framework* underscores that the lack of fundamental knowledge of science, engineering, and technology among U.S. workers and national decline in numbers of graduates in STEM programs necessitate the new approach to science education. To develop sufficient knowledge of science and engineering, and spark an interest in STEM fields, the National Research Council (NRC) of the National Academy of Sciences collaborated with practicing scientists, science educators, and engineering educators to develop the *Framework for K-12 Science Education* (NRC, 2012) which was used for the creation of the NGSS. In the *Framework,* the key science and engineering practices, disciplinary core ideas and crosscutting concepts are described in detail and in the NGSS, these three dimensions are blended to develop performance expectations which specify what students should learn and do by the end of each grade band (K-2, 3-5, 6-8 and 9-12).

The *Framework* made a distinctive emphasis on engineering education. The reasons for the inclusion of engineering in science education standards are outlined as follows: (a) the growing attention to the connections among science, technology, engineering, and mathematics for science education at the national level; (b) the connection between learning science and learning engineering and (c) the interplay between science and engineering: the distinction between applied science and engineering is blurry.

The *Framework*/NGSS suggest the integrating of engineering into the science education program as an instructional approach to teach science subjects:

> The committee thinks it is important for students to explore the practical use of science … Engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science—and, for many, their interest in science—as they recognize the interplay among science, engineering, and technology. (NRC, 2012, p. 12)

Therefore, as the practical use of science, the *Framework* puts emphasis on the integration of engineering design in science lessons. Along with this line of thinking, the NGSS recommends an integrated approach that blends the ideas of engineering and science with the practices to prepare informed future citizens who will be able to make decisions about nations' future.

The *Framework* describes engineering as "any engagement in a systematic practice of design to achieve solutions to particular human problems" (NRC, 2012, p. 11) and uses the term "engineering design" rather than "technological design" to provide consistency with its definition. Based on the *Framework*, the NGSS formulated the performance expectations related to engineering which require students to "define problems—situations that people wish to change—by specifying criteria and constraints for acceptable solutions; generating and evaluating multiple solutions; building and testing prototypes; and optimizing a solution" (NGSS Lead States, 2013 p.1, Appendix I). The *Framework* suggests that science and engineering education be structured around three dimensions: science and engineering practices, crosscutting concepts, and disciplinary core ideas.

The *Framework* states that engaging in engineering practices helps students understand the works of engineers and the interplay between science and engineering. Besides, students can recognize engineering as an endeavor dealing with major societal and environmental challenges as they engage in engineering practices to produce solutions to problems. Also, the *Framework* stresses the importance of engineering practices in science learning as "engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science" (NRC, 2012, p. 12). The *Framework* provides a diagram which represents the practices of science and engineering in three spheres (see Figure 2.1). The first sphere (investigating) includes components of empirical investigation. In this sphere, engineers engage in data collection to test their proposed solutions. In the second sphere (developing explanations and solutions), engineers construct design models to predict system behaviors and obtain data to test the validity of their predictions and then, optimize their design models. In the middle sphere (evaluating), engineers evaluate their designs iteratively at every step of their work. They generate evidenced-based arguments and critique their design models with their colleagues to ultimately improve their designs.

This diagram addresses important aspects of engineering: (a) engineering design is empirically based; (b) engineers engage in multiple iterations; (c) engineers evaluate their designs by arguing and critiquing with their peers; (d) engineering is model-driven.

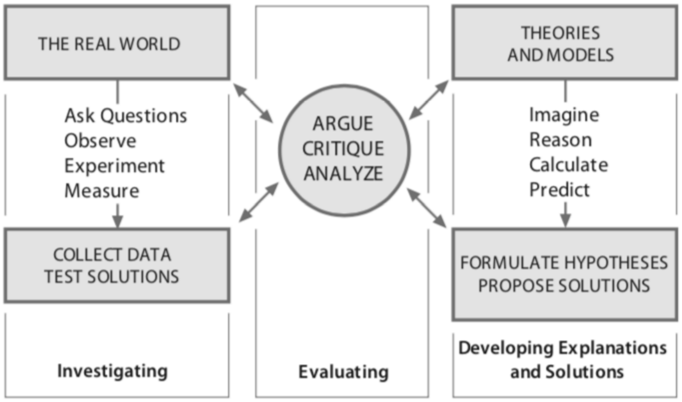

Figure 2.1 "The three spheres of activity for scientists and engineers"
Adapted from National Research Council 2012 (p. 45).

Also, the standards document specify the differences between science and engineering as follows: (a) while engineering is driven by immediate practical application, science is driven by curiosity or desire to understand natural world; (b) the purpose of engineering is to address and meet human needs whereas the purpose of science is to develop theoretical descriptions about the natural world; (c) unlike scientists, engineers make trade-off decisions between competing designs based on specifications and constraints and evaluate their design models and ultimately design the most effective solution; (d) while engineering designs should meet design specifications and constraints determined by the end-user of the product, scientific theories should meet different set of criteria such as parsimony and explanatory coherence; (e) as compared to science the aim of which is to provide a coherent and comprehensive explanation, the aim of engineering is to choose an optimal design solution among multiple possible solutions by taking certain design criteria and constraints into consideration.

The *Framework* proposes eight engineering practices for K-12 engineering education as follows:

> Asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematical and computational thinking, designing solutions, engaging argument from evidence, and obtaining, evaluating and communicating information (NRC, 2012, p. 3).

The Framework also underlined the iterative aspect of engineering as “In doing science or engineering, the practices are used iteratively and in combination; they should not be seen as a linear sequence of steps to be taken in the order presented” (NRC, 2012, p. 49).

Overall, the *Framework* explicitly defines the phases of the engineering design process that engineers go through in the *Practices* dimension. Also, there are several implicit and explicit recommendations for the important aspects of engineering in this dimension. Specifically, the standard documents address the following notions: (a) engineering designs are based on empirical evidence rather than trial and error, that there are multiple solutions to a problem; (b) engineers utilize models including simulations, sketches or physical prototypes to visualize, predict, test and evaluate their design; (c) engineers use cost-benefit and risk analysis, or predictions about market trends to provide arguments for their design solutions; (d) engineers work collaboratively; (e) engineering requires mathematical and scientific knowledge; (f) the work of engineers requires creativity and critical thinking, and communication skills; and (g) engineers engage in practices in an iterative fashion rather than a linear one.

In addition to *Practices* dimension, the aspects of engineering are addressed within the *Crosscutting Concepts* dimension. In this dimension, overarching themes for engineering appears alongside those for science. The *Framework* addresses how these conceptual frameworks are used by engineers and the importance of them in the engineering design process. Of these conceptual tools, the concepts of system and system models, and structure and function are given more emphasis as critical conceptual tools for engineering and engineering design process.

The special place is also given to engineering in the *Disciplinary Core Ideas* dimension. The *Framework* includes the core idea of engineering, technology, and applications of science which consists of two core ideas: engineering design and links among engineering, technology, science, and society. The *Framework* states that the inclusion of these core ideas helps students understand how scientific knowledge is applied through the engineering design process and the differences and relationships among engineering, technology, and applications of science. The standards put emphasis on the differences between engineering and science. In Appendix F, it is emphasized that "engineering design is not just applied science" (NGSS Appendix F, p. 1) and that their purpose and end products are different. To further clarify the differences, the definitions of engineering and the application of science are provided. The *Framework* defines engineering as "a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants" and application of science as "any use of scientific knowledge for a specific purpose, whether to do more science; to design a product, process, or medical treatment; to develop a new technology; or to predict the impacts of human actions." (p. 202).

The *Framework* suggests that the core ideas of *Engineering Design* as the domain of knowledge related to engineering practices. The *Framework* argues that although there is no general consensus on the complete set of core ideas in engineering, the engineering design is considered as a critical component of science and engineering education in K-12 settings by the committee because of its potential use as an instructional method to help students apply their scientific knowledge and to engage in engineering practices. This core idea comprises "defining and delimiting engineering problems, designing solutions to engineering problems, and optimizing the design solutions" (NRC, 2012, p. 203). In this section, the underlying concepts of engineering design are explained: (a) *Defining and delimiting engineering problems*: Engineering design process begins with defining a problem, and formulating specification of criteria and constraints; (b) *Developing possible solutions*: Engineers engage in brainstorming to discuss possible solutions in the light of the specified design criteria and constraints. Engineers communicate their design ideas through sketches, mathematical, graphical, or physical models; (c) *Optimizing the design solution*: Optimizing design solutions necessitates making trade-offs between competing criteria to find the best design solution among potential alternative solutions. The choice of the "best" design solution depends on value judgments and determining the most critical criteria for the design solution depends on the various factors such as end-users' preferences and needs, and its influence on environment and society.

The core idea of *Engineering Design* encompasses the detailed descriptions of the engineering design concepts of criteria, constraints, optimization, and trade-offs, and explicitly addresses the role of modeling and investigation/data analysis in the design process and the way engineers apply mathematics and computational skills to problems. Also, the *Framework* implicitly addresses the failure-laden nature of engineering in this section: "Tests are often designed to identify *failure* points or difficulties, which suggest the elements of the design that need to be improved" (p., 207). There is also another implicit recommendation regarding the creative process which is described as a critical component of the design process: "the creative process of developing a new design to solve a problem is a central element of engineering." In contrast to the previous science standards, the *Framework*/NGSS presents a relatively more holistic view of the engineering design process.

The second core idea, *Links Among Engineering, Technology, Science, and Society* embodies how science, technology, and engineering shapes society and how societal factors including political, economic and cultural factors affect scientists' and engineers' works as well as how these fields are different from and interwoven with each other:

Interdependence of science, engineering, and technology: advances in science, engineering, and technology continuously inform one another and push each other forward.

Influence of engineering, technology, and science on society and the natural world: advances in science, engineering, and technology have an impact on diverse domains such as medicine, agriculture, transportation, energy production, and water availability. In turn, society has an influence on science and engineering. Society's reactions to and decisions on social and environmental issues sometimes facilitate and at other times limit the work of scientists and engineers.

The NGSS specifies the performance expectations for the core idea of *Engineering Design*. On the other hand, although the *Framework* identifies the expectations for each grade-band for the core idea of *Links Among Engineering, Technology, Science, and Society*, the NGSS does not include any specific performance expectations for this core idea. Rather, the NGSS include this core idea in crosscutting concepts for relevant physical, life sciences, and Earth and space sciences core ideas.

In the NGSS, there are 36 performance expectations specifically addressing engineering in total. Fourteen of them are specific to the core idea of *Engineering Design*. Also, the NGSS mark the relevant performance expectations with an asterisk to indicate the integration of science concepts with engineering through practices or core ideas. Twenty-two performance expectations are marked with an asterisk to show the link between science and engineering.

Overall, the Framework/NGSS addresses the important aspects of the nature of engineering either through an explicit or implicit manner throughout the document (see Table 2.1).

Table 2.1
Concepts and Aspects of Engineering in the Framework/NGSS

Concepts and Aspects of Engineering	The Framework/NGSS Descriptions
Engineering design is empirically based	"Engineers engage in testing that will contribute data for informing proposed designs" (NRC, 2012, p. 45) "With data in hand, the engineer can analyze how well the various solutions meet the given specifications and constraints and then evaluate what is needed to improve the leading design or devise a better one" (NRC, 2012, p. 47)
Engineering involves multiple iterations/ The absence of a stepwise engineering design process	"In doing science or engineering, the practices are used iteratively and in combination; they should not be seen as a linear sequence of steps to be taken in the order presented" (NRC, 2012, p. 49)
Engineering is model-driven	"Engineers use their models including sketches, diagrams, mathematical relationships, simulations, and physical models to make predictions about the likely behavior of a system" (NRC, 2012, p. 46)
Engineering design solutions require collaboration and teamwork	"Engineers collaborate with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas" (NRC, 2012, p. 52)
Communication with peers is an essential part of the engineering design process	"Engineers cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively" (NRC, 2012, p. 53)
Engineering is not applied science/demarcation between science and engineering	"Engineering design has a different purpose and product than scientific inquiry" (Appendix I, p. 1)
Engineering provides solutions to human problems	"Any engagement in a systematic practice of design to achieve solutions to particular human problems" (NRC, 2012, p. 11)

Designing engineering solutions requires the application of scientific knowledge	“Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants” (NRC, 2012, p. 12)
Designing engineering solutions requires the mathematics knowledge	“Engineering, too, involves mathematical and computational skills. For example, structural engineers create mathematical models of bridge and building designs, based on physical laws, to test their performance, probe their structural limits, and assess whether they can be completed within acceptable budgets” (NRC, 2012, p. 65)
There are multiple solutions to a problem/The absence of single best design	“Multiple solutions to an engineering design problem are always possible because there is more than one way to meet the criteria and satisfy the constraints” (NRC, 2012, p. 209); “There is usually no single best solution but rather a range of solutions” (NRC, 2012, p. 52)
Engineering involves making trade-offs decisions between criteria and constraints	“Optimization often requires making trade-offs among competing criteria” (NRC, 2012, p. 209)
Engineering is socially and culturally embedded	“Not only do science and engineering affect society, but society’s decisions (whether made through market forces or political processes) influence the work of scientists and engineers” (NRC, 2012, p. 213)
Engineering design solutions require creativity	“Engineering and science are similar in that both involve creative processes, and neither uses just one method” (NRC, 2012, p. 46).
Engineering is failure-laden	“Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved” (NRC, 2012, p. 207)
System thinking and system models are important tools in the design process	“Engineers imagine an artificial boundary between the system in question and everything else. They then examine the system in detail while treating the effects of things outside the boundary as either forces acting on the system or flows of matter and energy across it” (NRC, 2012, p. 92)
Designing objects and systems requires the knowledge of the properties of materials	“The functioning of natural and built systems alike depends on the shapes and relationships of certain key parts as well as on the properties of the materials from which they are made” (NRC, 2012, p. 96) “Building a lighter bicycle may require knowledge of the properties (such as rigidity and hardness) of the materials needed for specific parts of the bicycle” (NRC, 2012, p. 97)

Engineering involves predicting and assessing implications of solutions	“Decisions about the use of any new technology thus involve a balancing of costs, benefits, and risks— aided, at times, by science and engineering. Mathematical modeling, for example, can help provide insight into the consequences of actions” (NRC, 2012, p. 212)
Engineering design solutions are developed through the engineering design process	“The design process—engineers’ basic approach to problem-solving—involves many different practices. They include problem definition, model development and use, investigation, analysis and interpretation of data, application of mathematics and computational thinking, and determination of solutions” (NRC, 2012, p. 204)
Engineering designs involve control mechanisms	“In designing systems for stable operation, the mechanisms of external controls and internal feedback loops are important design elements” (NRC, 2012, p. 98)

Even though the *Framework*/NGSS covers a wide range of epistemic aspects of engineering, several concerns could be raised with respect to the framing of engineering within the standards documents. While the *Framework*/NGSS committee repeatedly attempts to clarify their purpose for the inclusion of engineering in science education due to engineering’s potential to improve scientific knowledge by providing a context for applications of scientific concepts, the close examination of the documents can easily show that the authors of the *Framework* include engineering as a distinct subject throughout the practices, disciplinary core ideas and crosscutting concepts. Specifically, each practice and crosscutting concept are separately explained and described from an engineering perspective and three disciplinary core ideas with the performance expectations specific to engineering are included. That is to say, science and engineering are given equal priority in the standards documents as opposed to what the committee claimed about the integration of engineering as a pedagogical tool. Therefore, the inclusion of engineering into science education is confusing.

Also, the inclusion of engineering is not sufficient. Even though the *Framework*/ NGSS apparently emphasizes engineering as a distinct subject, it leaves students without a full grasp of engineering ideas. Specifically, although the Framework/NGSS addresses important concepts of engineering in either an explicit or implicit manner throughout the document (see Table 2.2), there is no conceptual framework that brings all engineering ideas together in the documents. Such a conceptual framework, which includes epistemic aspects of engineering could support students' meaning making of their engineering design experiences. Based on the feedback obtained from the science, engineering, and education committees, a number of appendices were added to provide clarifications and more details about the standards. The NGSS presents several aspects of engineering design that appeared throughout the *Framework* in separate documents (Appendix I and J). However, most of the aspects are not presented in these appendices and most importantly not included in the standards. In this case, teachers are expected to refer back to the *Framework* to address these aspects in their lessons. In this regard, in an article where McComas and Nouri (2016) raised their concerns about the place of Nature of Science in the NGSS, they argued that only a few teachers examine the *Framework* or NGSS Appendices while they are preparing their lessons. Instead, they focus heavily on the documents consisting of the standards. Therefore, the *Framework* misses the opportunity to provide a clear and well-organized section for the epistemic aspects of engineering to be included in the standards. Such a framework would allow teachers to infuse those aspects explicitly into science and engineering instructions.

Another concern is that the suggestion regarding the portrayal of engineering as a practical end of science could mislead teachers. This notion may in turn lead students to consider engineering as applied science although the standards documents present the difference between the two disciplines (e.g., Antink-Meyer & Brown, 2019; Cunningham & Carlsen, 2014). This confusion can only be cleared up by including a clear and distinct section devoted to epistemic aspects of engineering. Such a framework would also be useful to interpret the interrelationship between science, technology, engineering, and society.

Besides, several concerns raised by science education researchers and the engineering community concerning the inclusion of engineering in the standards. After the first draft of the standards was opened for review, the International Technology and Engineering Educators Association put forward that there is no consensus within the field about what concepts of engineering and technology are central to K-12 education. As a response, the *Framework* clarifies that engineering design is considered as the core idea of engineering with which there seems to be an agreement. Another concern is that the *Framework* identifies the core idea of engineering as practices of engineering design rather than its foundational knowledge. To be more specific, the disciplinary core ideas for engineering are labeled using verbs (e.g., Developing Solutions, Optimizing the Solutions) while the disciplinary core ideas for science are described using nouns (e.g., Motion and Stability, Energy). Several researchers argued that the conflation of terms can lead to confusion among teachers about knowledge and the use of knowledge (Cunningham & Carlsen, 2014: Cunningham & Kelly, 2017).

While previous science standards (SFAA, Benchmarks, and NSES) include engineering as a component of technology education, these standards documents do not reflect the full range of ideas related to engineering. However, the *Framework* and NGSS put a special emphasis on engineering and made engineering an integral part of science education. Table 2.2 presents the explicit and implicit recommendations of the standards concerning the epistemic aspects of engineering.

Table 2.2
Comparison of Explicit [E] and Implicit [I] Key Aspects of Engineering in the Science for All Americans [SFAA], Benchmarks for Scientific Literacy [BM], National Science Education Standards [NSES], and Next Generation Science Standards [NGSS]

Aspects of Engineering	SFAA	BM	NSES	NGSS
Engineering design is empirically based	-	-	-	E
Engineering involves multiple iterations/ The absence of a stepwise engineering design process	-	-	-	I
Engineering is model-driven	-	I	-	E
Engineering design solutions require collaboration and teamwork	-	-	I	I
Communication with peers is an essential part of the engineering design process	-	-	-	E
Engineering is not applied science/demarcation between science and engineering	I	I	I	E
Engineering provides solutions to human problems	I	I	E	E
Designing engineering solutions requires the application of scientific knowledge	E	E	E	E
Designing engineering solutions requires the application of mathematics knowledge	I	-	-	E
There are multiple solutions to a problem/The absence of single best design	E	E	E	E
Engineering involves making trade-offs decisions between criteria and constraints	E	E	E	E
Engineering is socially and culturally embedded	E	I	I	E
Engineering design solutions require creativity	I	-	I	I
Engineering is failure-laden	-	I	-	I
System thinking and system models are important tools in the design process	-	-	-	E
Designing objects and systems requires the knowledge of the properties of materials	-	I	-	I

Engineering involves predicting and assessing implications of solutions	I	I	-	E
Engineering design solutions are developed through the engineering design process	I	I	I	E
Engineering designs involve control mechanisms	I	I	-	E
Engineering requires ethical awareness	-	-	I	-

Research on Students and Teachers' Nature of Engineering Views

It is necessary to delve into the conceptions that students have about engineering before attempting to suggest ways in which engineering education can be structured to improve K-12 students' and teachers' conceptions of the nature of engineering.

Several studies attempted to examine students' conceptions about engineering to inform teachers' instructional decisions. These studies indicated that many students associated engineering practices with building and fixing and they viewed that the engineering profession mainly involves physical labor rather than a profession that requires conceptual knowledge and thinking skills (e.g., Fralick et al., 2009; Knight & Cunningham, 2004). In this strand, Knight and Cunningham (2004) developed the Draw an Engineer Test (DAET) by modifying the Draw a Scientist Test (DAST) to explore what students know about engineers and engineers' work. Three hundred eighty-four K-12 students were asked to explain what engineers do through drawing an engineer at work and providing explanations for their drawings. The students' drawings included images of activities such as building and fixing artifacts such as heavy machinery and tools, images of designing models, computers or desks, or bridges, trains, and engines. Therefore, the drawings revealed that students envisioned engineers as construction workers or car mechanics. Only a few students depicted engineers thinking or drawing their designs on paper.

In another study, Fralick et al. (2009) used the DAST and DAET to compare and contrast the perceptions of the 1600 middle school students with respect to engineers and scientists. Students' drawings indicated that students focused mostly on the physical aspect of engineering rather than the cognitive aspect. Specifically, they depicted engineers as a doer or worker bee. They drew engineers operating vehicles or building structures. As compared to scientists, most students drew engineers with no inferred action which indicated that students lack perception about the engineers' work and design process. Students also portrayed engineers wearing laborers' clothing outdoors. Further, students depicted engineers as being less scholarly than scientists. Particularly, they drew scientists with books, diplomas, mathematical equations, and as they engaged in thinking activities whereas they portrayed engineers with more tools. Therefore, the researchers concluded that students seemed to hold more informed views of scientists than they do of engineers, and they had insufficient knowledge especially about the cognitive aspect of engineering. In the same year, Mena et al. (2009) investigated elementary students' perceptions of engineering through using the DAET instrument, and Engineering Instructional Knowledge Test. Students were first invited to draw an engineer engaging in engineering activities and then, they were interviewed to explain their drawings and what they know about engineering and the engineering design process. The Knowledge test includes questions with regard to science and math knowledge, knowledge about the engineering design process, and engineering work that specialize in different branches. In this mixed-methods case study, they focused on three unique cases: the students from each grade level (K 3-5) who showed growth over time after participating in authentic engineering challenges. Mena et al.

found that the preconceived conceptions were varied across individual cases. One of the students described the engineer as an engine while the other student emphasized the physical aspect of engineering. Differing from the other cases, the third student put little more emphasis on the conceptual aspect of engineering along with the physical aspect of it. Specifically, she seemed to perceive engineering practices as designing and drawing prototypes. However, despite the differences across cases, students' initial conceptions of engineering were found to be insufficient in general.

By the same token, Capobianco et al. (2011) utilized the DAET to explore perceptions of the elementary students concerning engineering and engineers. The study aimed to reveal what students think about engineers and ultimately, inform standards and curriculum about how instructions could be planned and designed based on students' conceptions. Three hundred ninety-six elementary students in 20 classrooms were asked to draw an engineer engaging in engineering activities and then provide detailed explanations for their drawing. Then, four students from each class were further interviewed to elaborate on their drawings and explanations. Actions carried out and artifacts utilized by engineers were inductively analyzed and coded. The analyses unraveled four different conceptions of engineers that students had. First, most students depicted engineers as mechanics who repair engines (e.g., fixing a broken car) or drive vehicles (e.g., trucks, airplanes). Several younger students portrayed engineers as an object and an engine. Second, nearly 19% of students portrayed engineers as skilled laborers who build and make roads and buildings. Third, several students drew technicians who repair electronic devices (e.g., computer, television, telephones). These students thought that engineers hold some technical skills. Lastly, 6% of students, only fourth and fifth-grade students, conceived that engineers design buildings, electronic devices, and vehicles rather than fix or make them. Therefore, the results indicated that many of the students associated engineering with the term “engine” and engineer’s work with the action of “fixing”. Although the upper elementary students who described the work of engineers as designing products or buildings had relatively more informed views as compared to lower elementary students, the majority of the fourth and fifth-grade students still perceived engineers as mechanics. All in all, the technical aspects of engineering such as fixing, building, and repairing were found to be prevalent among students. Based on their findings and the existing literature, the researchers proposed a list of attributes of engineers that students should learn. Those included creative, collaborative, using science, mathematics, and technology, designing everything around us, and solving human problems.

In this strand, the National Academy of Engineering (2008) reported a study in which students’ perceptions of engineers and engineering were analyzed. It was found that many students seemed to have an understanding of engineering work including designing and building things. However, they had a limited view of what engineers do. Students conceived that engineering requires hard work and that engineers work mostly on computers in isolation with minimum contact with their colleagues.

Several studies developed and used different assessment tools to provide a more comprehensive analysis of students’ views of engineering. Karatas et al. (2011), for example, argued that having informed views of nature of science (NOS) influences students’ understanding of science content. By the same token, developing informed views of the nature of engineering (NOE) could help students improve their understanding of engineering. That’s why, in their study, they attempted to uncover what students already know about the engineering and nature of engineering. They investigated 6th-grade students’ NOE views by using students’ drawings and semi-structured interviews. They analyzed the engineering literature to specify the aspects of NOE. Those include that engineering is tentative, social and cultural embedded, iterative, collaborative, creative, that engineering depends on science and mathematics knowledge as wells as failures and success, involves analytical thinking and consideration of customers and the effect of engineering solutions on the environment, society and individuals, and that engineers design artifacts and systems and have a holistic and open system approach. The research methodology of phenomenography was employed to examine students' experiences which shape their perceptions about engineering. A total twenty 6th-grade students were interviewed, during which students were shown several pictures of engineering artifacts, and then, based on the pictures, they were asked questions with regard to the definition of engineering, engineering design process, the demarcation between science and engineering, and the influence of engineering on society. Besides, they were asked to draw engineers at work and explain their drawings. Students drew engineers mostly designing, inventing, creating, planning, fixing the products, and less frequently operating or driving vehicles, testing, and decorating assembling the products. Seven themes emerged from the analysis of interviews including who decides how an artifact should be built, engineers' work, attribution of other works to engineers, characteristics of engineers, design process, the influence of engineering work in daily life, and the demarcation between science and engineering. Nearly half of the students did not have any idea about who make decisions about building or creating engineering artifacts and products. Although most students thought that engineers involved in creating the artifacts, they seemed to mean that they involve in construction processes rather than designing processes. In line with that, students' responses about engineers' work indicated that most students viewed engineers as construction workers who fix, make, or build vehicles, structures, roads, etc. Relatively few students perceived that engineers engage in the design process by taking part in decision-making regarding how the structure should be built and testing the design to check whether it works properly. Only five students mentioned several design criteria and constraints that engineers should consider in a design process such as money, time, and size of the products. As for the attribution of other fields to engineering, nearly half of the students seemed to confuse the work of engineers with that of architects. Few students attributed the roles of factory or construction workers, mechanics, and scientists to those of engineers. Students also mentioned the characteristics of engineers such that they should be smart and creative, and that they need practical knowledge. Regarding students' views about the nature of the engineering design process, they were shown pictures of different versions of video game console that came out in different years and asked about how the designs change over time. Most students stated the reason for the design changes is to improve the product. Other reasons that students expressed included improving sales and meeting the needs of customers. Students also specified the criteria that engineers should take into consideration during the design process consisting of material selection, safety, durability, functionality, and aesthetics. As regards the phases of the engineering design process, more than half of the students included the building phase. Even though students discussed the imagination, planning, testing, and improving phases, no student included all phases. Most of the students thought that the engineering design process has two phases; one is planning and the other is building the product. When they were asked about the role of engineering in our daily lives, most students acknowledged the important role of engineering in developing new technologies. As for the demarcation between science and engineering, most students failed to explain the differences between those disciplines whereas only a few students pointed out that engineers design and construct while scientists study nature.

Several students thought that scientists study living organisms, while engineers carry out research on vehicles, structures, and engines. Also, few students focused on the similarities between science and engineering such as the goal of making technology and our lives better, building structures, using mathematics, and conducting experiments. Even, two of them thought that they are essentially the same. Furthermore, Karatas et al. (2011) analyzed the sources of students' conceptions. Those included TV, movies, courses and their teachers, etc. Overall, although the students in this study tend to perceive the engineering design process as mostly the process of building and making structures, and assembling the parts of vehicles, nearly half of them indicated that engineering is an active and dynamic process which includes planning, creating and testing. Also, students seemed to conceive engineers as skilled craftsmen. All in all, the researchers concluded that six-grade students had insufficient NOE views, except that of the role of engineering in society.

Later, Karatas et al. (2016) developed the VNOE questionnaire to examine first-year engineering students' NOE views, their beliefs about the features of a good engineer and the end-product of an effective engineering design process, and differences and similarities between their NOE and NOS views. 114 first-year engineering students were administered the twelve-item open-ended VNOE questionnaire. The inductive data analysis yielded six categories based on students' responses to the VNOE questionnaire: (a) the definition of engineering; (b) the engineering design process; (c) factors that affect the final engineering product; (d) features of engineering work; (e) attributes of a good engineer; and (f) the connection between science and engineering. Most students seemed to consider engineering as the problem-solving process while other students considered engineering as the application of science, the process of creating artifacts, ideas, and real-world products or systems. Few students thought that engineering is an attempt to discover how things work in order to improve them. Students also thought that the purpose of engineering involves improving engineering products, making the world and human's life better by solving human and environmental problems. As for the views of the engineering design process, most students stated that engineers need to take specifications of the product and constraints into consideration. Few of them emphasized the consideration of the purpose of the product and limited human resources. While the majority of students put emphasis on the cognitive aspect of the engineering design and they emphasized that engineers engage mostly in sketching, mathematical or graphical representation of the design, and supervise the construction of the design, few students believed that engineers engage in a building process. Also, it seems that the majority of students considered engineering as a solitary pursuit rather than a social endeavor requiring teamwork. Regarding students’ views about the factors that affect the final product, the majority of students thought that engineers’ different thought processes, experiences, and visions would affect the final product. Students determined the quality of engineering work based on the product-, client- and effect-oriented factors. Most students focused heavily on product-oriented factors such as functionality, efficiency, and specification of the product. When it comes to the attributes of a good engineer, students focused on their personal, intellectual, social, and ethical aspects, and background knowledge. Most students specified at least one personal characteristic of a good engineer including patience and determination. Also, nearly half of them stressed the importance of having good social characteristics in engineers’ work such as collaboration and communication skills. Other characteristics that students voiced included dedication, hard-work, open-mindedness, detail-orientation, creativity, intelligence, responsibility, and honesty. Lastly, students’ responses regarding the relationship between the fields of science and engineering revealed that nearly half of the students perceived that science and engineering are different, separate fields and that engineering is the practical application of science. However, the majority of the students did struggle to differentiate between the scope of science and engineering fields clearly. Only a few students emphasized the interdependence of both fields. Also, the majority of the students did not attempt to mention the role of understanding of science and mathematics in engineers' work.

After Karatas et al. (2016) completed the analysis of students' conceptions, they compared and contrasted the findings of the study and the Accreditation Board for Engineering and Technology (ABET)'s student outcomes. Based on the student outcomes, most students seemed to have a sophisticated understanding of the constraints that influence engineering work. On the other hand, the majority of the students in this study failed to describe the relationship between science and engineering. They underestimated the importance of the aspect of learning from failure. Although they emphasized that engineering involves the problem-solving process, they did not mention how engineers solve a problem or what kind of processes they follow to produce solutions. They did not recognize the importance and necessity of collaboration with individuals from different disciplines. Most students had uninformed views about multiple decision-making processes involved in the engineering design process and multiple factors could affect the ways in which engineers solve problems. Also, students did not address the ethical aspect of engineering as a characteristic of a good engineer and as a constraint for the design process. Good social and communication skills were not explicitly discussed by the majority of the students. Lastly, students seemed to lack knowledge about the tentative aspect of engineering, the role of previous experiences in the design process, and the difference between scientific experimentation and engineering design process in a real-life context. Overall, based on the analysis of students' responses, Karatas et al. (2016) suggested the integration of explicit instruction which addresses the aspects of the nature of engineering into engineering courses.

Based on the above-mentioned findings, one can conclude that students need proper and explicit instruction on the nature of engineering. On the other hand, the situation is not so different for teachers who are expected to change and improve students' knowledge about the epistemology of engineering. A significant number of elementary teachers feel unprepared and uncomfortable integrating engineering in their science instructions (Carr et al., 2012; Katehi et al., 2011; Moore, 2012; Trygstad et al., 2013). This is not surprising considering the previous studies reporting that elementary teachers did not receive training on engineering and how to teach it throughout their education (Cunningham & Carlsen, 2014) and less than 15% of K-12 teachers attended to at least one engineering-related course during their undergraduate program (Banilower et al., 2018).

In this sense, several studies unraveled teachers' conceptions and views about engineering (e.g., Lachapelle et al., 2006; Hsu et al., 2011). One of the most consistent findings of these studies was that teachers generally tended to place more emphasis on the technical aspect of the engineering design process rather than its social and cognitive/mental aspects. While creating and building are integral parts of the design process, a more complete view of the nature of engineering includes but not limited to the following: engineering design process requires problem-solving, planning, social interactions, imagination, applying science and math knowledge, data collection and analysis, and viewing the engineering design process as a cyclical iterative process rather than a non-repeating linear process. In this line of research, Lachapelle et al. (2006) inquired into the views of elementary teachers about features of the engineering discipline Even though the teachers correctly identified the purpose of engineering as producing solutions to human problems through technologies, the inadequate understanding was evident in most teachers' accounts with regard to the engineering activities, in other words, the ways that they produce technologies. The teachers conceived that engineering activities mainly involve building and construction, failing to acknowledge crucial activities that engineers mostly engage in, including problem-solving, using scientific principles, creativity, and collaboration.

In a similar vein, Hsu et al. (2011) examined the perceptions of the one hundred ninety-two elementary teachers as to engineering and how their perceptions were affected by their gender, ethnicity, and teaching experiences. They used the Design, Engineering, and Technology (DET) survey to reveal their perceptions about the importance of and familiarity with DET, characteristics of engineering, and the stereotypical characteristics of engineers. Results indicated that while teachers acknowledged the importance of DET education for students, they were found to be not familiar with DET. Given that they had not had pre-service and in-service training on DET, it is not surprising that they had low confidence in teaching it. As for the stereotypical views of engineers, they all agreed that minorities and females could be successful in engineering fields. Besides, they thought that engineers needed to have science and math skills for their work.

Likewise, Lambert et al. (2007) explored the conceptions of elementary teachers with regard to engineering after a two-week summer professional development program. Thirty-three elementary teachers were asked to describe what engineering is and what engineers do. At the beginning of the program, most teachers placed more emphasis on the physical/technical aspects of engineering design such as building and fixing rather than cognitive aspects of engineering such as creativity, problem-solving, collaboration, and communication. At the end of the program, it was indicated that most teachers acknowledged the importance of the cognitive aspects of engineering. Lambert et al. ascribed this change in the perceptions of the teachers concerning engineering to the professional development activities emphasizing the cognitive/mental aspects of engineering.

The impact of the conceptions of teachers on their classroom implementations has long been documented. In this line of inquiry, several scholars indicated, for instance, that teachers' conceptions concerning the nature of science had an impact on how they approach teaching nature of science in their classrooms (e.g., Schwartz & Lederman, 2002; Wahbeh, & Abd-El-Khalick, 2014). In that sense, it can be speculated that teachers' conceptualizations with respect to engineering could reflect how they incorporate it in their lessons. Put it differently, if teachers conceive engineering activities are all about technical problem-solving, they would engage their students in activities that require only technical abilities. In this respect, Wendell et al. (2019) went beyond this speculation and investigated how teachers' framing of engineering influenced their instructional practices. It was found that teachers framing engineering activities as a way of science sense-making guided students to inquire into underlying causes of design failures by examining empirical data and underlying scientific principles. However, teachers giving priority to the end-product of the design activities and its functionality engaged their students in prototyping, evaluating the effectiveness of the design, and encouraging them to apply scientific principles to build a design that fulfills the functionality criterion.

Several scholars also examined how teachers conceive NGSS science and engineering practices. In this line of research, Kang et al. (2018), indicated that even though teachers stated that they incorporated engineering practices in their engineering instructions through design activities, it was unraveled that none of the teachers adequately explained the NGSS engineering practices and the techniques to integrate them in design activities. In a similar vein, Antink-Meyer and Meyer (2016) uncovered several misunderstandings that teachers held about NGSS science and engineering practices: (a) the design process is guided by the design outcome rather than by the design problem; (b) science work should be completed before design procedure is implemented, mistakenly suggesting that engineering is applied science; (c) creativity is important only for the phase of planning during the design process and (d) the outcome of the design process should be tangible such as engineering artifacts, mistakenly excluding processes.

All in all, these studies demonstrated that teachers held naïve conceptions about engineering and activities that they engage in. But most importantly, they had misconceptions regarding the nature of engineering. Therefore, it is essential to develop a framework underlining the agreed-upon epistemic aspects of engineering to help teachers understand and integrate the framework as a conceptual tool to teach engineering conceptions to their students as well as engage them in meaningful design activities.

Research on Nature of Engineering Aspects

The emphasis on procedural knowledge without introduction of a conceptual framework has long been criticized by many scholars (e.g., Antony, 1996; Bell et al., 2003; Cunningham & Carlsen, 2014). Even though the process, operations, and dispositions are the pivotal elements of meaningful learning, it is established that these elements should be incorporated with conceptual knowledge. For example, Bell et al. (2003) designed a study with students to test a hypothesis that students could construct their own knowledge of the NOS and scientific inquiry from their inquiry experiences. After students went through scientific inquiry experiences, it was indicated that students' initial ideas did not significantly change, and they still had misunderstandings about NOS and scientific inquiry. In another study, Sandoval and Morrison (2003) sought to examine to what extent the engagement of students in scientific inquiry, without the explicit emphasis on science epistemology has an influence on their beliefs about what counts as science. The study indicated that simply engaging in the inquiry process or justification process was not enough to change or improve students' scientific epistemologies which led them to conclude that explicit epistemic discourse should be embedded in science instructions. All in all, the researchers suggest that explicit content instruction be embedded in instructions. Along with this line of thinking, researchers have turned their attention to formulate conceptual frameworks to be integrated into engineering instruction. Before the release of the NGSS, the research efforts devoted to identifying engineering concepts are limited to secondary level education (e.g., Childress & Rhodes, 2008; Custer et al. 2010; Harris & Rogers, 2008). Custer et al. (2010), for instance, attempted to explore engineering concepts in the literature on philosophy of engineering and technology, secondary level science, mathematics, technology, and engineering standards and engineering-oriented curriculum projects. Also, they conducted focus group sessions with practicing engineers and engineering educators to elicit their views about what engineering concepts should be included in secondary level education. Participants were first asked to identify core engineering concepts and then, categorize them into two subcategories "doing" and "knowing" in order to isolate conceptual knowledge from the processes. Document and focus group analyses yielded more than 100 themes that are crucial to engineering education. Of these concepts, engineering design was found to be the fundamental conceptual theme that could be used as a central theme to teach other aspects of engineering. The research team and focus group participants had difficulty to identify conceptual themes essential only to engineering because of two reasons. First, each engineering field (e.g., mechanical engineering, civil engineering) has distinctive analyses and processes to engage in which requires a specific range of knowledge. For this reason, generalizing core concepts across the fields could be challenging. Second, some of the engineering concepts could not be separated from other disciplines such as science, mathematics, and technology.

Although social and cultural aspects of engineering were not considered as core engineering concepts, Custer et al. (2010) argued that the interwoven relation of engineering with social and cultural issues should be included in secondary engineering education. Other important conceptual themes that emerged from this study were problem-solving and experimentation. Authors discussed that considering problem-solving as a conceptual construct rather than the practical basis of engineering design could raise several issues. Particularly, problem-solving is not peculiar to engineering. Problem-solving is a way of thinking which is used in most of the disciplines. Also, they speculated whether problem-solving could be taken into consideration as an overarching concept for engineering design. When it comes to experimentation, it was found to be more relevant to scientific disciplines. But they also argued that considering experimentation as an analysis of engineering theory is dependent on the extent to which engineering is conceived as a discipline of science. To improve the visibility of technology in secondary education, several scholars suggested infusing engineering design as it relates to technology into technology education (Wicklein et al., 2009). The overarching aim of integrating engineering design in secondary education is to equip students with necessary knowledge and skill for the post-secondary engineering education.

With the aim of integrating engineering into technology education, Childress and Rhodes (2008) utilized a modified Delphi technique to determine engineering student outcomes for secondary education. A total of 34 participants who had experience as engineers, experience as engineering educators and/or experience in the engineering-related position participated in the study. The researchers first reviewed the literature on engineering outcomes. They analyzed focus group studies, national standards, and other resources to prepare the initial list of student outcomes. Then, in the first three rounds of the Delphi study, 47 student outcome items were presented to the panel members and asked them to rate the items in terms of the relative importance of the outcomes for students who would like to pursue a career in engineering, if needed, add and reword items. The interquartile range (IQR) statistics were used to examine the rating responses. The consensus was achieved on 43 outcome items from a total of 54 items. These student outcomes were considered by the experts as either important (3 on a 5-point scale) or more important to include in the curriculum (4 or more). After the third round, the outcome items were categorized into groups according to their conceptual similarities. In the last three rounds of the Delphi study, the panel members ranked each category, which resulted in 7 engineering student outcomes categories. The student outcomes in the *Engineering Design* category stresses the importance of creativity and confidence in designing engineering solutions, the iterative nature of the engineering design process, and tradeoffs. The *Application of Engineering Design* category consists of student outcomes related to design activities which students should be able to engage in such as experimentation, optimization, prototyping, etc. The category of *Engineering Analysis* comprises outcomes concerning the use of science and mathematics in the engineering design process. The *Engineering and Human Values* category outcomes emphasize the effects of engineering solutions on society such as trade-off decisions between safety considerations and costs and/or ethics. The *Engineering Communication* category includes outcomes related to all kinds of communications such as presenting solutions and using computer-aided designs essential to the design process. The category of *Engineering Science* comprises the outcomes related to scientific knowledge that students should learn including an understanding of material properties, energy, power, etc. The last category, Emerging Fields of Engineering, includes outcomes with regard to nanotechnology, genetic engineering, smart technologies, etc. Of these outcome categories, the outcomes related to the *Engineering Design* were the most highly rated ones. Therefore, the researcher suggested that students engage in hands-on engineering design activities. Also, they recommended that instead of making engineering the focus of technology education, the outcomes underlined in this study should be integrated into technology education programs to improve learners' technological literacy.

Harris and Rogers (2008) also performed the Delphi method to consult opinions of engineering faculty members on what engineering-related competencies should be included in secondary science, mathematics, and technology education to prepare students for the college-level engineering program. In the first round, the expert panel which consisted of sixteen engineering and engineering technology professors from a wide range of engineering fields was invited to provide a list of competencies that they think are important in four categories: engineering/technology related, science, and mathematics-related and other. During the second round, the panel members were invited to rate the importance of each competency that emerged from the first round on a four-point Likert scale ranging from strongly agree to strongly disagree. In the last round, they were provided a list of the 41 competencies and asked to provide their professional opinions with regard to the relevancy of each competency to secondary engineering education. The panel members agreed on 38 competencies related to basic, technical, and interpersonal skills. The results indicated that the experts considered the competencies regarding basic and interpersonal skills such as communication and interpersonal skills, and ethic (non-technical skills) more important than those associated with technical skills such as engineering, science, and math-related skills. Among the engineering/technology related competencies, being able to sketch engineering designs, to operate fabrication equipment in a safe manner, to develop an understanding of engineering and engineering fields and to apply the engineering design process was considered the most important competencies for high school students. Of the mathematics-related competencies, having a high level of competency in algebra, trigonometry, basic computations skills, geometry, and the ability to perform graphing were determined as the most critical competencies. As for the science-related competencies, the ability to read meters, scales, and other instruments, to relate science concepts to mathematical ones and to develop physics skills were the highest rated competencies. Eleven competencies not aligned with the engineering, science, and mathematics-related competencies were categorized as other-related (non-technical) competencies. Those included the ability to communicate effectively, to develop a high level of reading comprehension, being honest and open-minded to new ideas, eager to learn, problem-solving skills, the ability to follow instructions, and having a strong work ethic.

In this line of research, National Academy of Engineering and National Research Council (NRC) (2009) which is one of the NRC reports that is used as a basis to develop the *Framework* (NRC, 2012) also highlights several epistemic aspects of engineering to be considered for improving K-12 engineering education. The report highlights three central themes: engineering design, application of science and mathematics, and engineering habits of mind. The report clarifies that the engineering "habits of mind" involve attitudes, thinking skills and values inherent to engineering and these consist of systems thinking, communication, attention to ethical issues, teamwork, and optimism. Also, this report suggests that the aspects of the engineering design process should be emphasized in the K-12 context. Those include that engineering design is an iterative process; that it provides a context for learning science, math, and technology concepts; that it may have multiple solutions to a problem and that it fosters systems thinking, modeling, and analysis.

After the engineering is infused into the recent K-12 science standards, several researchers attempted to investigate central aspects of engineering for K-12 science education. Moore et al. (2014), for example, developed a framework for identifying key components of quality K-12 engineering education. Key components were ascertained based upon the review of the relevant literature, the criteria established for engineering programs and professional organizations, document analysis of state standards, assessment of classroom practices and the implementation of curriculum, and the opinions of experts in engineering and engineering education fields. This framework was intended to enable educators, researchers, and policymakers to utilize it as an evaluation tool for evaluating the integration of engineering in lessons as well as the development tool to inform them about the future K-12 engineering standards. Moore et al. employed design-based research methodology which includes iterative revision cycles of developing framework based on previous research and documents, testing through expert review and application to standards, and revising framework. After five cycles of revision, 12 key indicators were identified for the framework. The first indicator was the *Complete Process of Design* which encompasses three sub-indicators: *Problem and Background*, *Plan and Implement*, and *Test and Evaluate*. Altogether, the engineering design process was found to be the central topic of engineering education. The other indicator, *Apply Science, Engineering, and Mathematics Knowledge* addresses the interdisciplinary nature of engineering. *Engineering Thinking* indicator represents the ways of thinking which are crucial to engineers including creativity, systems thinking, reflection, metacognition, learning from failure innovation, being able to provide solutions to problems. *Conceptions of Engineer and*

Engineering indicator emphasizes the understanding of engineering as a discipline and how they work which comprise the conceptions of engineering such as the importance of needs of clients and constraints for their design and that no single best design. Another indicator, *Engineering Tools, Techniques, and Processes*, specifies the techniques, skills, processes, and tools which are unique to engineering. *Issues, Solutions, and Impacts* indicator underlines the importance of understanding societal problems that we encounter today and the impact of the engineering design solutions on society. *Ethics,* as an important indicator, addresses the understanding of the importance of ethical consideration in engineering practices. *Teamwork* which emphasizes the importance of intrapersonal and collaborative skills in engineering practices and *Communication* which comprises the ability to communicate through multiple representations were also found as important aspects of engineering education.

In another strand, researchers put their effort to develop the nature of engineering (NOE) framework by establishing a connection with the nature of science literature (Deniz et al., 2019; Karatas, 2009). Deniz et al. (2019) stated that aspects of NOE implicitly addressed in the *Framework*/NGSS are similar to NOS aspects. From this perspective, Deniz et al. proposed the NOE framework can benefit from NOS literature and the NGSS recommendations relevant to engineering. Additionally, six engineering professors from mechanical, computer, electrical, and environmental and civil engineering were consulted for their opinions on the descriptions of NOE aspects. The framework includes tenets of “demarcation criteria”, “engineering design process”, “empirical basis”, “tentativeness”, “creativity”, “subjectivity”, “social and cultural embeddedness” and “social aspect”. The aspect of demarcation criteria is related to the notions of engineering as a discipline, and the similarities and differences between engineering other disciplines such as science, philosophy, and religion. The engineering design process aspect encompasses defining and delimiting engineering problems, designing engineering problems, and optimizing design solutions that are aligned with the NGSS recommendations. The aspect of empirical basis emphasizes that engineers collect and analyze data to test their models and compare alternative design solutions. The aspect of tentativeness addresses that the engineering design process is continuous testing and improvement rather than a step by step process. The aspect of creativity emphasizes the role of imagination in the design process. The subjectivity aspect underlines that there is no single best way to solve an engineering problem. The social aspect of engineering points out the role of collaboration in the engineering design process and the social and cultural embeddedness addresses the interwoven relationship between engineering and society.

In the same strand, Hartman (2016) attempted to conduct a three-round Delphi study to determine the nature of engineering views relevant to K-12 engineering education. Participants comprised 30 science teachers, engineering/technology teachers, science, and engineering education college educators. However, practicing engineers were not consulted in this study. Hartman adopted a mixed-method approach that encompasses both qualitative and quantitative analyses. In the first round, the participants were invited to list and explain all features of the nature of engineering which they think are appropriate for K-12 engineering education. In the second round, the participants were asked to assess each theme that emerged from the first round and then, rate them on a five-point scale. For the last round, a questionnaire was prepared based on both qualitative and quantitative data gathered from the second round. Participants rated the revised themes again and provided justification statements for their responses. The aspects of NOE were determined based on the established agreement level for consensus and stability. For this Delphi study, Hartman defined the criterion of consensus as at least 75% of panel members rating each NOE aspect at four or five on a five-point scale (important or very important) in the third round and the criterion of stability was defined as the consistency of responses for each NOE aspect in both second and third round. Based on these criteria, the study revealed eight aspects of NOE: (a) Divergent/*Multiple Solutions*: there are multiple solutions to a problem; (b) *Creative*: creativity is an critical component of the design process; (c) *Iterative/Learns from Failure*: design process requires multiple iterations and learning from failure is an important component of the iterative process; (d) *Model-driven*: engineers use mathematical, visual and/or physical models to test their designs and diagnose the failures; (e) *Communicative*: communication with peers is essential for the engineering design solution; (f) *Constrained by Criteria*: engineering design solutions are assessed based on specified criteria and constraints; (g) *Collaborative*: engineering design solutions necessitate team effort; (h) *A Unique Way of Knowing*: engineering as a way of knowing extends the engineering knowledge through the application of science and math knowledge and empirical testing.

Other themes consisting of *Design Process*, *Problem Focused, Ethical, Systems Thinking, Multidisciplinary* and *Contextual* emerged from the first and second rounds; however, they were excluded from the final list of NOE aspects since several of them were not stable between the rounds and for the others, the consensus was not achieved. Following the Delphi study, Hartman proposed several revisions on the list of NOE aspects. Although the *Design Process* theme is strongly recommended for engineering education in the *Framework* (NRC, 2012), participants of this study did not achieve consensus on this theme. In fact, although this theme had high mean ratings in the second round, the stability criterion was not met for this theme. In this regard, the author argued that this was mostly because some participants in this study raised concerns that students might misconceive the design process as a linear, step by step process. In this sense, Hartman suggested that the *Design Process/Design Driven* theme be included in the list of NOE aspects. Also, Hartman removed the *Creative, Communicative, and Collaborative* themes from the list since he suggested that these themes were related to the aspects of engineering practices rather than those of the nature of engineering. Further, Hartman suggested the *Unique Way of Knowing* as a main theme of engineering rather than an aspect of the NOE. After these revisions, the final list of NOE aspects includes five themes: *Design Process/Design Driven, Multiple Solutions/Divergent, Iterative/Learning from Failure, Model-Driven, and Constrained by Criteria.* Authors argued that these themes found in this study are largely consistent with those found in the previous studies and recommendations for engineering education (e.g., Karatas, 2009; NRC, 2009; NRC, 2012).

Also, several scholars have raised concerns about the framing of engineering in the *Framework*/NGSS and investigated the nature of engineering aspects and practices of engineering (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017; Pleasant & Olson 2018). Cunningham and Kelly (2017), for instance, claimed that the NGSS fails to provide a full range of epistemic practices of engineering and their definitions. The authors explored engineering practices rather than epistemic aspects of engineering since they described their views of epistemology as “the ways that knowledge is constructed through action and practice” (Cunningham & Kelly, 2017, p. 487) and they further clarified their purpose as “our emphasis is on actions taken in the world (designed, material, sociocultural) and not on a view of knowledge or epistemological beliefs.” (p. 488). Therefore, the authors identified key epistemic practices of engineering for K-12 engineering education. They conducted a literature review to examine studies of practicing engineers and engineering education. The review of literature unraveled sixteen epistemic practices of engineering subsumed under the four major categories as engineering in social contexts, tools and strategies for problem-solving, uses of data and evidence to make decisions, and finding solutions through creativity and innovation. The authors noted that these practices are not specific to engineering since similarities exist among fields such as science, but these practices reflect the aspects of how engineers work. The first category, Engineering in Social Contexts, comprises the epistemic practices of "*considering problems in context, making trade-offs between criteria and constraints, working effectively in teams and communicating effectively, seeing themselves as engineers, persisting, and learning from failure"* (Cunningham & Kelly, 2017, p. 492). The first aspect is related to the social-cultural embeddedness feature of engineering. Specifically, engineers work on societal problems and that's why determining design criteria and constraints in light of societal issues are important to the problem-solving process. Also, they assess the implications of their solutions in this social context. Another epistemic aspect fallen into this category is the social aspect of engineering. That is to say, design solutions are produced through collaborative work and communication with expertise within and across disciplines. In this respect, it is important to develop a positive engineering identity that is shaped within a community and requires learning from failures through persistence.

The second category, Uses of Data and Evidence to Make Decisions, includes methodological aspects of the engineering design process. Engineering design solutions are tested by collecting and analyzing data. Authors also discussed the two methodological approaches commonly used in engineering which are *the systematic method of experimentation and use of working scale models* (Cunningham & Kelly, 2017, p. 492). It was noted that these types of methodology are not only used in engineering but what is unique in engineering is that engineers use experimental parameter variation when no useful theoretical knowledge is found.

The third category, Tools and Strategies for Problem-Solving, consists of the practices of *applying mathematical and scientific knowledge, envisioning multiple solutions, considering materials and their properties, using systems thinking, and building and learning from prototypes* (p. 492). Authors highlighted that applying scientific knowledge as an epistemic practice does not mean that engineering is applied science. Optimizing solutions as an important component of the process of problem-solving requires considering and assessing alternative solutions, and the materials used to produce technology. System thinking is another critical component of the design process. Engineers need to take into consideration structure-function relationships for their design. In addition, developing models and prototypes allows engineers to test and analyze their models. Not always data are drawn from experiments in the engineering design process, prototypes also constitute the data for analysis of design models. The last category, Finding Solutions Through Creativity and Innovation, comprised the epistemic practice of *innovating processes, systems, and objects.* Cunningham and Kelly revealed based on the studies of practicing engineering that the importance of creativity and imagination in finding innovative solutions was acknowledged by engineers.

In a similar vein, Pleasant and Olson (2019) examined the documents on the philosophy, history, and sociology of engineering in order to unearth the important nature of engineering aspects. This review produced nine NOE aspects that highlight the important characteristics of the engineering discipline. It was suggested the integration of explicit instructions on the following NOE aspects in engineering lessons. *Design in engineering* was identified as the unique feature of engineering that distinguishes engineering from most disciplines. The aim of designing artifacts that fulfill the desired function is what makes engineering design different from the other designs. Collaboration with engineers was also highlighted as an essential ingredient feature of the engineering design. *Specification, constraints, and goals* are conceptualized through social negotiations between clients or a technology firm and then through these negotiations, engineers translate them to quantitative specifications. *Sources of engineering knowledge* that engineers integrate into their designs include science and mathematics knowledge as well as knowledge about existing technologies. *Knowledge production in engineering* highlights the knowledge that is produced by engineers in industrial research or laboratories. That knowledge was called engineering science encompassing knowledge regarding the functions of technologies, and analytical methods. *The scope of engineering* does not reflect all technological work as engineers, for instance, do not typically involve in the design production phase. Also, not all inventions are created through engineering work. Technological design is the only activity that all engineers engage in but rather some engineers are more involved in the knowledge generation process, or in other words, engineering science. *Models of design process* underline that design models vary depending on their purposes. Descriptive models aim to identify essential design practices while descriptive models aim to provide suggestions regarding effective design processes. However, design processes could differ in terms of specific design context. The design models in the form of flowcharts could be used as a teaching tool for beginning designers but expert engineers also prefer to use flowcharts when coordinating work of engineering teams or when engaging in complex design problems. However, expert engineers usually tend to use prescriptive design models due to design constraints. *Cultural embeddedness of engineering* underlines how engineering has an influence on society and how society informs engineering problems since engineers design for developing solutions to societal problems. The theme also emphasized the responsibility that engineers have regarding the potential impacts of their designs on society. *The Internal culture of engineering* discusses the cultural features of the engineering community. The use of reductionism, problem-solving approaches specific to the engineering discipline, attention to details, and perseverance were considered as the important features for engineering. Also, unequal proportions of gender and minorities in the engineering discipline were also addressed. Lastly, *Engineering and Science* points out the demarcation between science and engineering. Science plays a crucial role in the engineering design process; however, scientific knowledge is not all that the engineering design demands. Science and engineering overall have different goals along with different approaches.

In the same line of research, Antink-Meyer and Brown (2019) reviewed the engineering and technology standards, along with the documents on the philosophy of engineering to develop a framework for the nature of engineering knowledge (NOEK). Seven key features of NOEK developed from this review are as follows: *Engineering is solution-oriented* endorses the idea that engineers work toward solving human problems and have the desire to serve humanity. Besides, they design for creating new products or improving systems or processes. Engineers, contrary to common assumptions, are not only designing engineering artifacts but also systems and processes. *Engineering is contextually responsive* underlines that engineers use trade-offs to balance between design criteria and constraints, in other words, human values and needs, and resources. Also, this category emphasized that design artifacts evolve through iterations when new information arises. *Engineering is empirically based* highlights that empirically based nature engineering is what differentiates between artistic designs and engineering designs. Engineers use data and models to obtain feedback about the effectiveness of the design and for optimization processes. *Engineering has a personal dimension* that emphasizes the role of creativity and subjectivity in the design process which results in different design artifacts. Engineers' personal, professional experiences, training, and assumptions affect their engineering decisions. *Engineering is influenced by societal and cultural factors* discusses how social and cultural issues can often become decisive factors in engineering work. Also, this theme stresses the implications of engineering designs on society, together with desirable and adverse effects. Genetic engineering was provided as an example of how designs could have direct implications on society. *Engineering is a social process* focuses on the importance of team-based engineering activities. Engineers through collaborations co-constructs engineering designs. Also, this theme addresses social interactions with clients/customers. The last theme was *Engineering is interdisciplinary* underlines the co-dependent relationship among engineering, technology, and science. However, this theme also underscores the importance of engineering science which is unique knowledge to the engineering discipline.

In another line of inquiry, Gunckel and Tolbert (2018) reviewed the place of engineering in science standards. Based on this review, the researchers raised several concerns about the portrayal of engineering in the NGSS. The authors argued that technical knowledge alone is not sufficient in engineering to produce solutions to today's increasingly complex global issues. They claim that designing environmentally and socially responsible solutions require engineers to act with care and empathy. Engineers should take into consideration the potential impacts of their designs on society and the environment. Therefore, the authors suggested that rather than putting emphasis mainly on technical aspects of engineering, developing empathy and care be integrated into K-12 education as important aspects of the nature of engineering.

Specifically, Gunckel and Tolbert (2018) criticized the technocratic, utilitarian, and neoliberal perspectives of engineering that are emphasized in the NGSS. As a decision-making approach, technocracy addresses that all human problems can be solved through technological solutions without considering political and social aspects of solutions and problems. The authors pointed out the overemphasis of the role of science and engineering knowledge in a problem-solving process that the NGSS provides. Such an approach underestimates the importance of the underlying social and political reasons for human problems and focuses only on technical issues. They also provided real-life examples that indicate how this approach fails to solve human problems. For instance, the design of high yield corps does not reduce famine since it is a political problem rather than a technical problem. Another issue raised here is that identifying problems on the basis of what people need and want to change imply that humans can and should use the natural resources for their own benefits to develop solutions. This perspective does not acknowledge the impact of using natural resources to produce technological solutions.

The authors listed several NGSS performance expectations that address this technocratic perspective. It was highlighted that one of the NGSS performance expectations, for instance, suggested finding solutions to global issues, considering only technical issues. The authors, thus, challenge this view since it does not take social and political solutions into account to address the sources of global problems. Therefore, it was suggested that the socio-cultural and political dimensions of the problems should be emphasized in the standards along with the technical aspects.

The second concern raised by the authors was related to the utilitarian perspective of engineering reflected in the standards. The authors argued that the framing of the engineering solutions as benefiting all people equally disregard issues of justice. The authors provided an example of the design of the hydroelectric dam to elaborate on this perspective. The design of a hydroelectric dam can provide a solution to an energy problem for a community, but this solution may not benefit to least advantaged members of this community and at the same time may create several environmental problems. The authors criticized that the *Framework* portrays engineering from this utilitarian perspective. The standards underlined that the criteria for the utility are determined based on the needs and wants of the end-user of the technology. This view does not take people who have no voice in the decision-making process into account. For instance, for the performance expectation of “evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts”, the authors discussed that there is no guidance for students to consider the impacts of the engineering design solutions from a more environmentally and socially responsible perspective. Also, in the *Framework*, the adverse impacts of engineering design solutions are framed as unanticipated results. The authors discussed that such a view fails to recognize the moral and ethical responsibilities of engineers for the environment and society. The third and last concern discussed in the article was the dominance of neoliberal ideology in the standards. Neoliberalism is defined as “an economic and political system that encourages the privatization of public institutions and uses market forces to control and exploit populations” (Gunckel & Tolbert, 2018, p., 947) and neoliberal educational policies establishes the goal of education as preparing students for future STEM jobs. In this regard, the authors pointed out the arguments of the *Framework* and NGSS for the inclusion of engineering in K-12 education settings. The main argument of these documents is structured around the need for the workforce in the private market. Also, the authors raised concerns about the effects of neoliberal values on the portrayal of innovation and creativity in the standards. For instance, the *Framework* puts forward that the adoption of technological innovations is determined by the evaluations of scientists, engineers, and government regulations as well as market forces. It was also highlighted that these neoliberal values are also evident in the market-based discourse of the standards. This view portrays engineers as the workers who work on the problems of those who can pay. Therefore, the authors criticized that the *Framework* and NGSS fail to engage students in the moral decision-making process with respect to societal and environmental issues. Overall, the authors recommended that ethics, empathy, and care be integrated into K-12 engineering education. Specifically, engineering education should help students understand social and environmental ramifications of engineering design solutions from a social justice perspective in addition to technical aspects of the engineering design process.

All in all, several studies have revealed and suggested important epistemic aspects of engineering appropriate for K-12 education. However, there is apparently little consensus on these aspects. To consolidate our current knowledge about the epistemic aspects of engineering, there is a need to investigate what epistemic aspects are fundamental to engineering knowledge, the design process, and institutional and social practices of engineering so as to inform policymakers, researchers, and educators. Also, in the relevant literature, there is apparently no Delphi study, which included practicing engineers in the decision-making process to identify the epistemic aspects of engineering for K-12 education. Hence, I will propose a Delphi study, the aim of which is to elicit the opinions of experts including practicing engineers preferably from different engineering branches and from different cultural backgrounds, science and engineering educators, and science education researchers on epistemic aspects of engineering.

Epistemology for Engineering Education

The question of what students should learn about engineering underlines the necessity of examining epistemological underpinnings of engineering discipline. Along with this line of thinking, the purpose of the current study was to explore epistemological commitments to what counts as engineering and engineering practices that are valued by the science and engineering community. Epistemology, the theory of knowledge and knowing, is a branch of philosophy that explores the origins, nature, scope, general basis, methods, and limits of human knowledge (Coffey, 1917; Goldman, 2004). Examining views on what counts as knowledge necessitates a disciplinary-specific approach as the perspectives of disciplinary knowledge are influenced and shaped by established epistemological commitments within the particular community (Sandoval, 2003). That's why the conceptions of the nature of engineering held by experts from a wide range of disciplines are valued and explored in this research to ascertain the epistemic aspects of engineering and ultimately, to make informed decisions about what epistemic aspects should be an integral part of the K-12 education. In the science education context, the ideas framing in science education have been informed by the work of philosophers, sociologists, historians, and practicing scientists who have attempted to identify the norms, characteristics, and practices of the discipline of science. One of the most influential examples of this is identifying and tailoring the aspects of nature of science for K-12 students to improve their conceptions about the epistemology of science and help them conceptualize science as a way of knowing. The core NOS ideas for science education has been identified through extensive reviews of literature in history and philosophy of science (e.g., Lederman, 1992; McComas, 1998), and consulting expert communities' opinions (Osborne et al., 2003). In this study, my attempt was to perform a literature review on the history and philosophy of engineering in order to compare the ideas framing in the literature with the experts' opinions on the epistemology of engineering to provide a further validation for the findings.

Exploring epistemological foundations of engineering is an attempt to understand how engineering knowledge and its processes are different from the other forms of knowledge and practices. However, it is critical to note that these features are not necessarily unique to the engineering field. The disciplinary boundaries separating engineering from the other disciplines often become blurred because solving human problems and designing new technologies require knowledge and reasoning grounded in a wide range of fields such as science and mathematics. For instance, the epistemological aspects of engineering may indicate similarities with those of science, and these two disciplines continually and reciprocally inform each other. Both engineering designs and scientific knowledge rely on empirical evidence. Collaboration and ethics are essential aspects of both disciplines. The history of science and engineering informs us about the mutual relationship between engineering and science clearly. For example, Michael Faraday's scientific work on magnetism drove him to design the electric generator and the Wright Brothers' design of airplanes led him to formulate the aerodynamic principles (Cagan, et al, 2005). Therefore, one can easily infer that both disciplines become less distinct. Still, the purpose and the end product of these two disciplines are different. While the main goal of science is to understand and develop explanations about the natural world, the aim of engineering is to solve human problems by designing new technologies. Hence, in this study, the researcher focused on the unique epistemic features of engineering with the features that intersect with other disciplines to inform K-12 engineering instructions and standards.

Another important distinction that needs to be considered is the ontological differences between engineering knowledge and engineering practices. In science education literature, the studies drawn from the research on philosophy, history, and sociology of science proposed a set of nature of science aspects. Those include that (a) scientific knowledge is developed on the basis of empirical evidence, (b) relies on observations and inferences, (c) is subjective, (d) is creative, (e) is tentative, (f) affects and is affected by social and cultural valued, (g) scientific theories are different kinds of knowledge (Lederman et al., 2002). Later, Schwartz et al. (2008) made a distinction between the nature of scientific knowledge (NOSK) and the nature of scientific inquiry (NOSI) as NOS aspects relevant to the scientific knowledge and as NOSI aspects specific to the process of inquiry. It is important to provide some conceptual clarity especially when seeking to elicit experts' opinions and eventually establishing the key epistemic aspects of a knowledge base for education. For example, Osborne et al.'s (2003) study which attempted to elicit experts' opinions about which aspects of science should be an integral part of the science education indicated that experts mainly underscored the aspects of NOSI- the process of scientific knowledge generation with a much less discussion of the NOSK. Also, the NGSS (2013) included the epistemic aspects of engineering practices as a disciplinary core idea with less emphasis on the aspects of engineering knowledge. Therefore, to establish a clear and comprehensive framework for the epistemic aspects of engineering, it is required to make a distinction between the aspects of engineering practices and the aspects of engineering knowledge.

The Literature on Philosophy and History of Engineering

In this section, the literature review on the philosophy and history of engineering was presented in terms of themes reflecting the epistemic aspects of the engineering discipline. The philosophy of engineering is an emerging research area that has gained focus in recent years with the contributions of philosophers of technology, historians of engineering and/or technology, and engineering educators. The themes derived from this ever-evolving literature were categorized by the researcher based on a systematic review. It is worthy of noting that this review was conducted after the data analysis of the Delphi study was completed in order to be able to systematically compare and contrast the findings of this study with the themes that emerged from the literature on the philosophy of engineering.

Knowledge Base for Engineering

According to the traditional view, engineering as a discipline has been mostly associated with the technical problem-solving process and practical applications and thus, much less with cognitive capabilities. If engineering was all about practical work or intentional act, this then begs the question of how technologies shaping our world were designed through a mere intentional act. In reality, “intentions alone have not put humans on the moon.” (Kroes, 2012, p. 4). In this regard, philosophers of engineering and technology take a closer look at the discipline of engineering. The main conclusion drawn from the analysis was that engineering designs are generated through both mental work (e.g., using knowledge, generations of creative ideas) and the physical world (engaging in technical work, constructions).

In that regard, several scholars studying the philosophy of engineering and technology have attempted to describe the nature of knowledge that engineers utilize. Engineers often benefit from knowledge about the natural world to produce engineered solutions. Luegenbiehl (2009) highlighted the use of knowledge from natural sciences in modern engineering as follows: engineering is “the transformation of the natural world, using scientific principles and mathematics, in order to achieve some desired practical end” (p. 153). As he emphasized, this definition of engineering “reflects the modern scientific foundation of engineering, rather than the crafts tradition” (p. 153). Besides, Vincenti (1990) underscored the necessity of the use of knowledge in engineering discipline as “what engineers do depend on what they know” (p.3). Engineering, therefore, is required to incorporate a practical problem in abstract scientific principles to create viable solutions. Engineers should exploit the advances in science whenever it is necessary; when for instance, exploring the better ways to solve problems, when learning from experience, and when continually improving their skills and knowledge base (Voland, 2004). Modern engineering problems are so complex that scientific theories and laws are necessary to deal with them. This implies that engineers need to use science in order to base their engineering decisions and solutions on.

In that regard, Vincenti (1990) discussed that the knowledge that engineers use is not pure scientific knowledge which is based on natural sciences but rather the knowledge that is being transformed for practical applications. Therefore, as several scholars underlined, engineering is more than merely applied science. Vincenti (1990), for example, challenged the view of "studying the epistemology of science should automatically subsume the knowledge content of engineering" (p. 3). Vincenti (1990) examining the designs of airplanes in his book "What Engineers Know and How They Know it", asserted that engineering designs typically rely on the knowledge of natural laws and theories; however, airplanes were not built by science. He emphasized the gap between scientific knowledge and engineering design, which can be closed by the art of engineering. An engineering historian, Henry Petroski (1992) emphasized the point in his book "*The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems"* as "relying on nothing but scientific knowledge to produce an engineering solution is to invite frustration at best and failure at worst" (p.45). Therefore, engineers transform scientific knowledge to integrate it into the design process to produce engineered solutions. Although this knowledge is grounded in science, the way in which engineers and scientists use that knowledge is different. Put it differently, as Vincenti (1990) argued, this knowledge differs in terms of specifics and is used distinctively in engineering. Sheppard et al. discussed that the use of scientific knowledge in the design process is not deductive but rather constructive and creative.

For instance, the concept of thermodynamics is presented to engineers differently as engineers need to use control volumes by which technological devices can be examined in a closed system.

Scholars argued that knowledge about the natural world is not all required to produce engineering designs. In contrast to common perception, which assumes that the knowledge base of the engineering discipline is predominantly rooted in the knowledge about the natural world, Vincenti (1990), for instance, suggested: “treating science and technology as separate spheres of knowledge” (p. 4). Likewise, Radder (2009) argued that it is very simplified to think that the goal of engineering is to construct technologies and processes that possess a socially useful function as engineering encompasses the creation and utilization of the design knowledge, which is vital for the discipline. Likewise, several scholars contended that engineering is predominantly based on practical knowledge. To illustrate this point, Figueiredo (2014) presented a case from prehistoric times. Our ancestors in the Early Stone Age discovered that by sharpening the edges of stones, they could create useful tools for hunting, and the exploration of the ways to improve their tools could in turn paved the way for the discovery of novel practices. This demonstrates that practice in the use of tools or artifacts produced knowledge concerning how to create and improve them. Figueiredo (2014) underlined that this was beyond mere blind trial and error procedure, and more of what Dewey (1974) identified as intelligent action that represents a mutual relationship between knowledge and practice; one continuously informs and advances the other. This is also similar to what Dias (2014) called reflective practice. Dias suggested that engineering knowledge mostly derives from practice and therefore, the reflective practices, which is about reflecting upon practices and actions that are performed by individuals in a profession or discipline, can create practice-based knowledge or “knowing-how”. As Dias underlined, although some theoretical knowledge is necessary for engineering activities, engineering knowledge is mostly based on engineering judgment, “rules of thumb” (established guidelines), and codes of practice (specific guidelines).

Several other scholars also attempted to formalize the knowledge that pertains to the engineering discipline. The important distinction was made among “knowing that”, “knowing how”, knowing when” and “knowing why” (Dym & Little, 2000; Sheppard et al., 2006; Ryle, 1984). The knowledge that engineers benefit and apply when designing includes knowing how to execute the design process, knowing theory and facts, as well as knowing how to use the appropriate knowledge for tasks at hand and when to perform particular phases of the engineering design process. Besides, Vincenti (1990) attempted to categorize engineering knowledge as follows: “fundamental design concepts, criteria and specifications, theoretical tools and quantitative data, practical considerations, and design instrumentalities” (p. 208). The category of the design concepts includes knowledge about the operational principles of a device and its normal configurations. Operational principles are related to knowledge about how the structure of the engineering design relates to its function while normal configurations indicate the shape and arrangements of the essential components of the engineering design. These two types of knowledge that engineers must integrate into the design process, in which normal design is carried out; however, they are usually unknown in radical designs, and thus, they are needed to be determined by engineers. Design criteria and specifications compose of technical requirements that the engineering design has to meet. Engineers need to translate qualitative objectives of the design into quantitative ones in order to specify the criteria and specifications. Besides, engineers exploit theoretical tools including scientific theories and mathematical methods, and approaches to carry out design calculations. The empirical data and sometimes theoretical data are required to evaluate the overall performance of the device. The quantitative data involve both descriptive data (e.g., physical constants, physical properties, and physical process) and prescriptive data (standards for the design regulated by the organization, safety factors, etc.). Practical considerations, consisting of practical knowledge specific to the engineering design intended to be designed, are also needed to address pragmatic concerns. For instance, in order to make trade-off decisions, one needs to know about the design, its use, its costs, etc. Practical design experiences or rules of thumbs play a crucial role in developing such considerations. Lastly, design instrumentalities comprise procedural knowledge concerning the engineering design process or knowing-how such as knowledge about how to perform optimizations, trade-off making decisions, etc. Further, Jonassen et al. (2006) claimed that engineers mainly count on experiential knowledge. The scholars claimed that engineers most of the time call on their historical knowledge regarding engineering problems rather than their conceptual knowledge and thus, using historical information is the most common strategy to solve problems.

Buch and Pederson (2015) stressed that engineers use any knowledge that is relevant and useful, no matter what its origin for a particular problem. The knowledge that engineers use could vary depending on the specific context (e.g., particular engineering problems, engineering projects, and the engineering discipline (Sheppard et al., 2006). On the other hand, Bunch and Pederson (2015) attempted to provide a general overview of the engineering knowledge base by proposing a pyramidal structure that organizes the knowledge base for the engineering discipline. In this structure, the bottom layer comprises fundamental knowledge including science and math knowledge while the middle layer represents the core knowledge specific to the engineering domain including knowledge concerning design procedure and analysis. The top of the pyramidal structure comprises deep knowledge that experienced engineers hold which enables them to designate the appropriate methods for a particular problem and find new approaches to an engineering problem. Buch and Pederson (2015) highlighted the difficulty to identify a unique epistemological basis for engineering discipline given that the knowledge base is constantly evolving and expanding. Likewise, Sheppard et al. (2006) identified the nature of the knowledge base of engineering as dynamic since the technologies evolve over time and thus, engineers should follow the current advancements in technology to stay up-to-date. From this perspective, technological knowledge referring to knowledge about the current technologies is viewed as essential to the engineering discipline, and given the fact that technological solutions continuously advance, it is important for engineers to update their knowledge base.

Bunch and Pederson (2015) argued that engineers need to incorporate a practical problem in abstract scientific principles to create solutions. Therefore, the engineering design process involves both "abstract theoretical knowledge and normativized concrete practical knowledge" and both types of knowledge should be intertwined together in the design process (p. 124). In a similar vein, in his book, Vincenti (1990) defined engineering as "the practice of organizing the design and construction, and operation, of any artifice which transforms the world around us to meet some recognized need." (p. 7). He further contended "any detailed analysis of engineering knowledge runs the risk of seeming to divorce such knowledge from engineering practice . . . the inseparability of knowledge and its practical application is in fact a distinguishing characteristic of engineering." (p. 207). Sheppard et al. (2006) elaborated on the interconnectedness of knowledge and practice in engineering. During the process, engineers recognize the gaps in their knowledge necessary to solve problems, they call on the knowledge base to fill in the gaps and then, synthesize that knowledge to integrate into the design process to find a solution.

Vincenti (1990) touched upon the common misconceived notion regarding engineering. To be more specific, engineers are typically conceived as the knowledge users while scientists are considered as the knowledge producers. On the other hand, engineering works also generate knowledge with successful designs and design failures as well as with knowledge gained through experience (Dias, 2014; Sheppard, 2006; Vincenti, 1990). Besides, Vincenti (1990) indicated several engineering cases in which engineers conducted experimental parameter-variation method when scientific knowledge is not available necessary for engineering designs, thereby producing new knowledge. In that regard, it is worth noting that engineers not only use existing knowledge to produce engineering solutions as commonly assumed, but also engineers create new bodies of scientific knowledge through the engineering design process. Radder (2009), for instance, challenged with Bunge's idea of engineering designs being the outcome of the applications of science (hierarchical view) and illustrated their point with several examples from historical studies such as, mechanical clocks, water power devices, metallurgical techniques, which were designed independently from scientific theories and facts. Likewise, Madhavan (2015) indicated that airplanes were built before the field of aeronautics emerged. Also, as one of the important products of the industrial revolution, steam engines helped to develop the principles of thermodynamics. Vincenti (1990) also presented engineered examples such as the pyramids of Egypt and the roads of ancient Rome in order to point out that several designs such as these were not created based on scientific knowledge as it was not available at that time but on the basis of the engineering knowledge. Lastly, in modern engineering, the design of the Mars rover, and the designs used for deep-water oil exploration were created when the information about the scientific conditions was not available and thus, engineers applied heuristics to the design problems (Koen, 2013).

Engineering Design

Design is considered by many scholars as to the core dimension of engineering. Whether a general framework that characterizes the design processes and identifies domain-independent procedures and characteristics for the design process can be developed has been a topic of philosophical debate (Kroes, 2012). On the other hand, there are plenty of engineering design models proposed in the literature many of which slightly differ in terms of subtasks and the aspects of each phase. For example, some engineering design models give a separate place for the need identification and others usually subsume the need identification into the problem definition stage. The theorists or educators of such models stressed that following strictly the phases in the models does not guarantee "successful" designs; however, the idea behind these proposals is to enhance the engineering design practices (Kroes et al., 2009).

In this strand, Rubinstein (1975) who defined the engineering design process as constrained-based problem-solving, for instance, proposed three clusters of activities for problem-solving. The first cluster, problem identification, activities involve defining the current state, the real problem, or need. The problem may be related to natural and political catastrophes, market demand, or technological opportunities. The second cluster, attribute, and constraint identification, activities focus on describing the desired features, specifications, and requirements of designs as well as their functions and costs. Finally, the third cluster, means-end development, activities aim to describe the path to achieving solutions; what procedures ought to be used to produce solutions to problems. This procedure uses means-end analysis requiring a comparison between the current state and desired end outcome, the solutions. The first two cluster activities are important to determine the direction of the process. Given that engineering problems are ill-defined, engineers pay much more attention to describing the problem and specifications. The means-ends analysis demands generating, evaluating, and implementing design ideas that require data- and model-driven process (Sheppard et al., 2006).

In a similar vein, numerous scholars have attempted to propose models that characterize distinct stages for the design process, but most of which represent overlapping ideas. van de Poel (2009), in this strand, proposed five distinct stages for the design process. In the stage of the problem analysis and formulation, engineers engage in the development of design requirements and a plan for the actions that need to be taken to achieve the solution. In the conceptual design stage, engineers develop alternative viable solutions to the engineering problem at hand as well as possibly reframe the design problem, and in the next stage, they choose the one possible solution. They, then, move to the embodiment design stage in which they construct the chosen conceptual design in accordance with its structural and material criteria. In the final stage, the detailed design, engineers work on the details of the design that eventually enter the production process.

Likewise, Voland (2004), for instance, identified six different stages including needs assessment, problem formulation, abstraction and synthesis, analysis, and implementation. Engineers start with identifying the need for a solution, the objectives to achieve that solution, and the target end-users that will interact with the solution in the end. Engineers need to have an end in their minds at the beginning even if the end is subject to change during the design activity. They, then, begin to formulate the design problem in the form of design goals. They call on any knowledge necessary to conceptually establish the problem. Besides, the design specifications and resources that will be used during the design activity are identified during the phase of problem formulation. In the next phase, abstraction and synthesis, alternative conceptual solutions, and approaches to solve the problem are generated. Engineers sometimes search for existing solutions and/or ways to solve similar problems. Next, the conceptual abstract design options are evaluated in light of the design criteria. This phase encompasses the practices of identifying strengths and weaknesses of the alternatives, evaluating them in terms of ethical implications, anticipating failures in the alternatives, and constructing prototypes to test, evaluate, and revise the alternatives. Lastly, in the implementation phase, engineers fully construct and produce the “successful” design which passes the prototype testing and obtain feedback from the experiences of end-users for future design activities.

Earle (1990) proposed a sixth-step model of engineering design process consisting of problem identification, preliminary ideas, problem refinement, analysis, decision, and implementation. Considering that the majority of engineering problems are not well-defined, engineers need to clearly establish the problem before moving forward to solve the problem. Earle suggested that the problem be comprehensively studied, taking into account the sources of the need, historical and personal observations, economic, market, and social aspects of the problem. The sources of need could be related to existing design shortcomings, poor conditions, need for a solution, or market potential. In that regard, engineers could engage in the data collection process in which the data concerning societal trends, similar designs, market value, etc. could be collected and examined to frame the design problem. Additionally, the design criteria along with the design requirements and limitations should be specified. In the next phase, preliminary ideas, engineers need to envisage as many solution ideas as possible. The initial solution ideas should be comprehensive enough to enable engineers to find unique solutions and ways to approach the problem. In this phase, the data concerning the opinions of end-users about preliminary ideas for the design could be required to make informed decisions about the steps that need to be taken. Also, engineers translate their idea solutions into sketches. The design refinement phase includes the selection of the most viable solution ideas to refine the preliminary ideas before the construction phase. To do so, engineers develop detailed technical drawings reflecting the physical properties, dimensions, and overall structure of the design. The analysis phase involves the evaluations of alternative solutions to determine the strengths and weaknesses in terms of function, cost, and market value. Models are used as an analytical tool to evaluate the features of the designs. The analysis may include functional analysis, economic analysis, market analysis, strength analysis, model analysis, etc. In this phase, engineers take advantage of any knowledge necessary for the analysis including technical, scientific, and math knowledge as well as experiences. Next, the most viable design ideas are retained and others are eliminated. Engineers usually decide on a single design idea relying on data to proceed to the implementation phase in which a chosen option needs to be presented as a functional design.

Dieter and Schmidt (2009) proposed a problem-solving method for the engineering design, which starts with the need recognition phase in which the needs that are usually related to problems with prevailing situations require to be identified. The needs could be related to reducing cost, enhancing performance and reliability, or changing in social/public trends and interests. Following, the problem definition requires writing a problem statement embodying the true nature of the problem, what the engineering design is expected to achieve, the goals, design constraints situated in the design context and design criteria to be utilized to assess the design. Engineers need to collect as much information as possible concerning the possible designs through which they can determine the elements, mechanism, and configurations that fulfill the design requirements. In the evaluation phase, engineers undertake testing and evaluation of models, or prototypes through two types of checks: mathematical checks and engineering sense checking, or in other work, engineering judgment. In the light of the evaluations, optimization techniques are used to enhance the quality of the designs. The authors cautioned against the iterative nature of the optimization process, which enables engineers to continuously improve their designs and emphasized the design constraints such as time and budget because of which the optimization process needs to be stopped at one point. Lastly, engineers properly communicate their designs through written reports as well as oral presentations or otherwise it may lose its value. Dieter and Schmidt (2009) reminded us that communication is a vital part of the whole design process, not limited to only one phase. Communication tools therefore may also comprise technical drawings, computer simulations, models, and functional prototypes.

There is an apparent consensus on the importance of the problem definition or identification phase among scholars (Dieter, 1991; Dym & Little, 2004; Earle, 1990; Voland, 2004). In this phase, engineers craft the initial definition for the problem, and then, explore the needs of clients, safety issues associated with the product, and economic aspects of the product, and then, construct the definition of what an acceptable solution is. Design problems, therefore, reflect the desires and needs of the target end-users (e.g., Dym et al., 2005). Contextual needs and problems originating from social, economic, and military objectives, as assumed, are considered as the primary sources of engineering problems but those are not the only sources of problems that create a need for engineering design. Engineering problems also arise from technological sources including “functional failure of current technologies, extrapolation of past technological successes, imbalances between related technologies at a given period and potential technological failures” as well as “perception of a new technological possibility” (Vincenti, 1990, p. 202-203). Dieter and Schmidt (2009) asserted “The true problem is not always what it seems to be at first glance.” (p. 10). Engineering problems should be defined as broadly as possible and reframed as needed. Even a small change in the problem definition could result in a different final product.

Many addressed that engineering problems are by nature ill-structured or wicked. In the engineering design process, problems are rarely well-defined (e.g., Vermaas, 2015). Although engineers initially have well-defined problems, as engineers move to the next steps where constraints, unforeseen problems come into focus and specifications are revised or modified based on feedback, engineers gain new insights for the problem, the engineering problems turn into more ill-structured problems (Buchanan, 2009; Jonassen et al., 2006; Vermaas, 2015) or even wicked problems (Bulleit et al., 2015). With the changes faced during the design process, the interpretations of the original problem are revised or changed, thus enabling engineers to identify new alternative solutions (Vermaas, 2015). Due to this nature of engineering problems, the engineering design process does not usually produce definitive solutions through even rigid procedures. Rather, engineers reconceptualize complex problems to facilitate the process.

All models, even though, present the phases in a linear or circular diagram, the scholars underlined the iterative nature of the process (e.g., Dieter & Schmidt, 2009; Earle, 1990; van de Poel, 2009; Voland, 2004).

Any attempt to describe the engineering design process as problem-solving is more likely to miss critical aspects of the design process. Given the fact that engineering problems are frequently ill-structured or wicked, which implies that engineers may have no clear idea about the design problem, and in turn, indefinite criteria to evaluate viable solutions and unclear solution space. Consequently, the design process also comprises establishing design objectives and criteria that are critical to the design process.

During the design process, it is necessary for engineers to be open and expand their thinking to obtain as many potential solutions as possible in the conceptual design phase (Voland, 2004). "Engineering is not deterministic" (Schmidt, 2014, p. 108). Subjective elements and context-dependent values playing a role in the design process may lead to multiple solutions. The best way to proceed from multiple solutions is to set the priorities and focus on the best way to approach the solution when there is no single best design solution. Engineers constantly face ill-structured problems and other uncertainties since there are various pathways or methods to solve an engineering problem (Dym et al., 2005; Jonassen et al., 2006). Besides, different engineering designs with the same function could be created to address the diverse needs and preferences of end-users. Also, cultural diversity and aesthetic traditions of societies account for the diversity in engineering artifacts each of which has a certain meaning and manifests different cultural and aesthetic values (van de Poel, 2009).

However, in the engineering discipline in which a pragmatic approach is favored, engineers need to choose the solutions that best address the needs and desires of end-users. Suckiel's (1982) argument for pragmatism provides a good description for what this solution selection process is like "the main criterion for choosing among different kinds of descriptions is not whether one is truer than the other. Rather we look to see which description is more appropriate, given the purposes we have in view." (p. 132). In this regard, as Simon (1977) put forward, engineers, when selecting design solutions, are not looking for the best solution but instead the most "satisficing" or in other words, good enough solution because in this case, they do not need to compare all possible solutions with one another but rather they compare solutions with the established design specifications.

To find a satisficing solution in light of design criteria, they use formal and informal analyses which may include both quantitative and qualitative analyses. The most commonly used analysis methods could comprise material analysis, risk analysis, environmental balance, cost-benefit analysis, and value or criterion-based decision-making procedures as well as discourse-oriented analyses (Banse & Grunwald, 2009). Besides, multiple criteria design analysis is often used during the design activity to evaluate the alternative designs and in turn, make trade-off decision making (van de Poel, 2009). This evaluation is performed by comparing and contrasting different values or design criteria associated with the design. Designers usually use a ranking method to determine the relative importance of each value for the design.

Modeling and prototyping are two important prominent practices that are regarded as an integral part of the design process, In the design process, modeling of working devices is considered as a vital practice in representing the complex engineering problem in a more concrete way. Individuals cannot portray reality as it is or visualizes it in an exact way. In that sense, models act as a mediator to represent human contact with reality (Bulleit, 2015). All types of models including mathematical, physical, scientific, or conceptual models are invaluable for engineering work. Modeling enables engineers to explain, predict and control the performance of engineering designs and systems (Bulleit et al., 2015; Zwart et al., 2013); to systematically create alternative solution ideas (Zwart et al., 2013); gather reliable quantitative data to evaluate their design options and to determine the most “sufficient” one (Vincenti, 1990; Zwart et al., 2013

); creating a context for collecting data to improve models (Bulleit et al., 2015); optimize individual aspects of design solutions; minimize the complexity of the design process by constructing a simpler model; work with uncertainties by presenting a model with particular assumptions; communicate the diverse alternative solution ideas and envision and facilitate the control of the processes planned (Zwart et al., 2013). Engineers may need to develop multiple viable models since unique, one-size-fits-all models are uncommon for design solutions.

The most frequently used models in the design process are drawings or conceptual models created either by hand or programs like CAD software program (Jonassen et al., 2006). Another type of model is physical working prototypes. Some claimed prototyping is at the heart of the design process when the knowledge related to the product of interest cannot be formalized. With prototyping, engineers can test and validate their solutions (Vinck, 2003). One of the main aims of using models is to obtain feedback related to failures, constraints, and trade-offs (Madhavan, 2015; Pirtle, 2010). The primary function of models in the design process is to base engineering decisions on as good models inform about the strengths and weakness of the current design, in other words, “good models provide a reality check for optimization” (Madhavan, 2015, p. 81) since models are used to indicate the function of the product intended to design, how the artifact or a system could work after it is built (Bulleit, 2017). In this way, models or prototypes make engineers much closer to end-users’ needs and desires since they can obtain feedback from them through models (Vinck, 2003). Pirtle (2010) illustrated how conceptual designs play a crucial role in an engineering design which mainly uses the trial-and-error process when no information was available. In the process of designing flush rivets, conceptual designs guided engineers in the testing phase and in turn, illuminate the optimum standards for the possible design solutions.

Reflection practices are seen as an essential part of the design process by several scholars. Engineers need to constantly check whether a revision or a change is needed for the problem definition throughout the design process (Earle, 1990; Voland, 2004) and the definition becomes more detailed with every new information through the problem analysis (Dieter &

Schmidt, 2009). Reflection, then, is conceived as an important component of the process of design (Voland, 2004) as formal reflections could be used to make informed decisions about the next actions, improve designs, and learn from experiences that eventually inform the future design activities. Engineers need to discuss their final thoughts and reflections at the end of the design process (Voland, 2004).

Trade-off decision making is another component that is essential to the engineering design process in which engineers need to engage in the trade-off decision-making process for both technical and non-technical reasons (Schmidt, 2014). To be more specific, when several design specifications or values can conflict, trade-offs need to be made. For instance, van de Poel (2009) identified several values that could conflict during the design process. Efficiency and effectiveness, for instance, are two important values that can be used to determine to what extent the engineering design function as intended and these two values can conflict during the design process. An effective charger can charge the phone faster but at the same time, it may need to use more energy to do so. What it is called an optimal solution is the solution that resolves this conflict between values (van de Poel, 2009; Voland, 2004).

Cost-benefit analysis is also an integral part of the design process in order to optimize designs (van de Poel, 2009). The designers need to discount the potential benefits of designs and their costs to determine their current values. The decision concerning the deduction rate may have a huge effect on the outcome of the design process. Engineers usually determine to design solutions that have greater potential benefits than their costs. The cost-benefit analysis is typically conducted to maximize one main value that could be economic values or non-economic values such as ethical or moral values. One, for example, can try to maximize the human quality of life or happiness.

Several scholars also touched upon the non-linear nature of the engineering design process. Buch and Pederson (2015), for instance, discussed that engineers work under multiple uncertainties throughout the design process including lack of necessary knowledge and facts and that they have to think the consequences or impacts of engineering design from a variety of perspectives including, but not limited to social, ethical, political and economic (Vincenti, 1990). These highlight “complex and heterarchical settings” where design processes are performed (p.123), which leads to a non-linear design process. Besides, there are innumerous changes and revisions taking place between the original goal and designed artifact due to the exploratory nature of the design process, feedback obtained from end-users and/or stakeholders resulting in revising design criteria, even problems and chance factor playing role in industrial context (Vinck, 2003).

Engineering as an Interdisciplinary Discipline

The design process involves technical activities that are performed within a social context in which scientific principles, end-user, or society’s needs and desires, as well as ethical codes and the norms and practices of organizations all, play a part (Bucciarelli, 1994). Engineering, therefore, incorporates knowledge from natural, social and other technical sciences in the practices of engineering (Banse & Grunwald, 2009)

This approach to social and technical dualism in engineering is related to the place of social science knowledge in the design process some of whom called this is a hybrid form of engineering knowledge (Sørensen, 2009). That means that new engineering design solutions are not created through straightforward applications of scientific knowledge. Engineers formulate engineering problems and make their engineering decisions based on the assumptions regarding human behaviors such as social needs, desires, interests, and trends. Therefore, it is vital for engineers to approach their work by using a combination of knowledge about the natural and social worlds.

Figueiredo (2008) proposed four major categories for the epistemology of engineering which clearly show the interdisciplinary nature of engineering: (a) engineering as basic science; (b) engineering as social sciences; (c) engineering as design and (d) engineering as doing. In the category of *basic science*, key aspects were identified as the application of natural sciences and the values of science adopted including logic and rigor. The category of *engineering as social sciences* encompasses underlines understanding of the social world, social practices in the discipline, economic, and social values. With regard to *engineering as design*, engineering is described as the art of design that highlights the non-scientific modes of thinking, system thinking, uncertainties, holistic and contextual approach rather than partial approach. Lastly, *engineering as doing* stresses the art of doing, the value of the ability to change the world, and addressing barriers with flexibility and adaptation. Figueiredo (2008) viewed engineering as rather a transdisciplinary discipline in which the four categories of the engineering epistemologies. To be more specific, engineering incorporates the key aspects of the epistemologies of four categories into a meaningful whole.

Engineering Design as a Social Process

The myths about engineering requiring mere technical competencies fall apart since several ethnographic studies exploring the nature of engineering practices has unraveled that social interactions with multiple individuals, teams and companies are an essential feature of engineering discipline (e.g., Bucciarelli, 1994; Bunch & Pederson, 2015; Dym et al., 2005; Vinck, 2003), thereby social interactions intimately intertwined the design process. Engineering similar to science is a human social activity shaped by specific social, cultural, and institutional factors (Lemke, 2001).

Horst Rittel, an early design theorist, argued that the engineering design process is "inherently argumentative" meaning that engineers need to continuously negotiate with others with regard to the pros and cons of viable solutions and engineering decisions (Rittel & Webber, 1973). Many other scholars argued that communication is at the center of the engineering discipline which requires explanations of how the engineering design is designed, used, or maintained (Dieter & Schmidt, 2009; Trevelyan, 2014; Voland, 2004).

Dym et al. (2005) proposed different types of communication used throughout the design process. Engineers communicate through different forms of language or representations. To be more specific, these may include (a) verbal or textual statements utilized to articulate design artifacts, specifications, and requirements as well as communicate multiple individuals and document the process and design artifacts; (b) graphical representations used to produce visual descriptions of design artifacts including, but not limited to, sketches, drawings, illustrations, etc., which allows engineers to keep viable design solutions, determine the pros and cons of each of them as well as revise solution ideas; (c) shape grammars utilized to represent design artifacts through formal shape rules which enable engineers to create complex shapes by using simple shapes; (d) features utilized to gather geometrical shapes associated with particular functions; (e) mathematical or analytical models utilized to describe the functions of design artifacts and (f) numbers used to describe the design parameters or mathematical models.

Bucciarelli (1994) which closely studied the practices of engineers in three different engineering firms, for instance, observed two visions of the engineering design process: savant's vision and utilitarian's vision. Savant-like engineers give priority to the application of scientific and technical knowledge, as well as the engineering design procedure and less emphasis on social processes while utilitarian-like engineers recognize the importance of collective work and social interactions in engineering. They mostly tend to view communication and negotiation as an essential part of the design process. Utilitarian-like engineers begin the design process with understanding the social needs of end-users/consumers, thereby viewing engineering designs as tentative, always subject to change based on social needs or problems. Bucciarelli, in his ethnographic study, highlighted that engineers view the objective of their design differently; each engineering field with different knowledge, standards, codes and instruments shape engineers' object world in which they live, thereby having different perspectives and responsibilities in the design process which eventually leads to distinct viewpoints with respect to their professions. His study indicated, therefore, that contemporary engineers work in multi-disciplinary teamwork where argumentations and negotiation occur among people from distinct object worlds. Likewise, Vinck (2003) in their review of engineering teams indicate the dominance of collaborative work with constant communication and negotiation throughout the design process, thereby revealing the social nature of the engineering discipline. Also, Trevelyan (2010) identified the ability to collaborate with others necessary for conscientiously carrying out the design process as an essential activity in the engineering discipline. In their study, in which engineering practices were examined in six different engineering firms, Anderson et al. (2010) also illustrated that communication and coordination which involve social interactions with clients and stakeholders are crucial to problem-solving processes. With the complexity of current engineering design projects as well as increasing specializations within the discipline and time-bounded nature of engineering works, the design process requires collaborative work and contributions of many people to the solutions. Meyers et al. (2010) underlined that one of the important factors describing the engineering discipline is the ability to work in teams.

Hence, Engineering work emerges from more of collective actions than an individual's actions (Bocong, 2015; Voland, 2004). In that regard, the engineering discipline is viewed as a broader human social activity instead of the traditional view of engineering being technical decision-making and problem-solving. One can say, therefore, both technical and non-technical elements are crucial for engineering design.

Engineering Design as a Creative Activity

The skill of creatively thinking outside the box is valued and considered as essential to the engineering problem-solving by the community of engineering (Anderson et al., 2010; Dieter & Schmidt, 2009; Pahl et al., 2007). Unlike traditional trial and error, intelligent action is situated in the heart of engineering practices (Figueiredo, 2014), requiring thinking to perform the "rehearsal (in imagination) of various competing possible lines of action" (Dewey, 1930, p. 190). Dewey considered that knowledge could not be a sole end of the problem-solving process but instead imagination was a necessary part of the process that should be combined with the action. Design problems are generally open, ill-structured problems, and therefore, engineers need to reformulate the problem to construct a closed, well-structured problem is not a deductive act but rather a creative one in itself (Dorst & van Overveld, 2009).

Earle (1990) contended that creativity is needed most during the conceptual design phase in which engineers brainstorm to generate as many solution ideas as possible and the design refinement phase. As engineers proceed to the next phases of the design process, the need for creativity diminishes when the information and data are needed to evaluate and make judgments about the effectiveness of the design solution.

Some scholars also argued that creativity and innovative thinking are necessary for generating solutions that resolve value conflicts. To be more specific, resolving value conflicts through new engineering designs is an important driving force of innovations in engineering (van de Poel, 2009).

Engineering Design as a Decision-making Process

The Accreditation Board for Engineering & Technology [ABET] (2018) characterizes the process of engineering design as a decision-making process rather than merely a problem - solving process. Considering the design process as simply problem solving may lead to misunderstandings since the presiding view that the problem-solving process is about focusing on “the best” solution is not applicable to engineering work. The engineering design is about dealing with finding sufficient solutions to ill-structured problems based on given constraints and criteria. The process involves making decisions on alternative designs and trade-off decision making among the variables and values. For this reason, engineers make decisions as they progress through the design process. Those decisions, then, have a huge influence on the design objectives and the outcome of the design activity (Dym et al., 2005; Kroes, 2012). Hence, these different kinds of decisions are an integral component of the design process. The “decisional” nature of engineering activities also demonstrates that the design process is not a process of discovery, but rather than a process of the invention. The reason for this, instead of engineers making decisions about pre-established or existing alternative solution ideas, they generate viable solution ideas during the design activity and by making decisions on which alternative best reflects what they intend to design, they agree on the final design (Kroes, 2009).

Engineering Design as an Empirically based Activity

The bottom line is that engineering designs are not based on *a priori* assumptions. Engineering designs are data-driven since engineering is not a "cut-and-dried practice" but rather observations and analyses are important activities in engineering, thus engineering design is not a priori (Vinck, 2003, p. 50). Engineers invest a significant amount of time in obtaining, interpreting, comparing and contrasting, and debating on the basis of evidence that they collaboratively described. They are using a wide variety of instruments and devices to obtain data by which they make decisions about the effectiveness of products as well as foresee errors and even disasters (Jonassen et al., 2006; Kerr, 2016). Empirical data plays a critical role in the optimization phase of the engineering design process (Madhavan, 2015). The data needed to evaluate and optimize designs may be also calculated theoretically (Vincenti, 1990).

Engineering Design Under Uncertainty

Engineering design is not characterized as an instrumental process since engineers often find themselves in uncertain situations in which problems turn to be ill-structured or wicked problems, there is not sufficient knowledge necessary to design solutions and constantly changing specifications, and thus, failures frequently happen (e.g., Bucciarelli, 1994; Madhavan, 2015). In fact, well-structured problems are rarely found in the real world where the problems are far from being simple (Dorst & van Overveld, 2009). In this sense, engineers regularly need to make practical decisions despite ambiguous and uncertain knowledge (Vincenti, 1990). When the lack of certainty persists and gives rise to significant ambiguity or doubt, engineers tend to direct their efforts to test and base their decisions on empirical data (Vincenti, 1990). The degree of uncertainty increases in non-prototypical systems in which simply generating physical prototypes are not possible (Bulleit et al., 2015) as well as in the design systems including human and environment interactions in the system of operation such as nuclear power plants or electrical grid. The factors generating uncertainty during the design process could consist of time (predicting the future of the design of interest and lack of knowledge regarding previous designs or approaches), statistical limits (inadequate empirical data with respect to actual behavior and performance of a design), model limits (low predictability of the design models due to simplicity of aspects of the design structure), randomness (the structural properties of designs could vary) and human error factor (Bulleit, 2008). Expert opinions and formal analysis could be used to reduce the uncertainty in the design process.

The degree of uncertainty varies depending on the type of design. In prototypical engineering systems, models and physical working prototypes can be constructed to evaluate the performance of designs during the design process. These designs such as machines typically have a short life span and can be easily revised or replaced. In contrast, in the large-scale non-prototypical engineering systems such as structures, it is not feasible to develop physical prototypes during the design activity. For that reason, feedback that can reduce uncertainty in making engineering decisions comes from the performances of actual designs or failures. In this sense, the feedback required to design safer engineering designs is obtained through failures.

Engineering as Heuristics

"The engineering method is the use of state-of-the-art heuristics to create the best change in an uncertain situation within the available resources." (Koen, 2013, p. 116). Hence, engineers use any kinds of knowledge that assist in the design process to find a particular solution to Like in many other fields, engineering practices continuously develop in the engineering community through shared knowledge, experiences, and explorations which result in the generation of heuristics that are eventually used by the members of the community and incrementally developed into better practices (Bulleit et al., 2015).

Engineering in Society

Engineering, as one *way of worldmaking,* gives humans the power to restructure the materials infused in our lives and our social environment by building technologies and systems (Lavelle, 2015). That means engineering through technology transforms the natural and social world. In that sense, Layton once described engineering as “an instrument of social change and social revolution’’ (Layton, 1991, p. 74). On the other hand, engineering should not be viewed as an external agent influencing the society and environment. Instead, the engineering discipline is an integral part of society and it is codependent and coevolves together with society (Newberry, 2015b). In other words, engineering cannot be considered to exist independently from the social, environmental, political, and cultural contexts within which it is being carried out. For this reason, the engineering decision making process deals not only with technical problems but it has to be also entangled with various issues including, economic, political, ethical, social, etc. (Bunch & Pederson, 2015). In this sense, following a design process with fidelity is not the only criterion to create “successful” designs. Understanding the problems of society as well as human behaviors and integrating them into the design procedure is another important integral component of engineering. Engineering design beyond the use of scientific knowledge and technical concerns embodies inherent social concerns with regard to practical solutions (Schmidt, 2014).

Engineers view themselves as mediators between the natural world and society. While they are exploiting the natural world, they produce for the benefit of society which humanizes the discipline to a certain extent (Picon, 2004). In this regard, Newberry (2015b) highlighted the dialectical tension between the ideals of the engineering community and what they have achieved for society in reality. Even though the ideals of engineers are to benefit society and transform the world in a constructive and positive way, the applications of their designs in real life would not have the same effects or sometimes have reverse effects on society and the environment. There are always risks for unintended and unforeseen consequences of the engineering designs. Also, sometimes the benefit is not distributed equally to all people which may further deepen the inequality issues.

Since most engineering designs directly infuse in every aspect of our lives, the societal implications of engineering designs are an important aspect of engineering that should be thoroughly considered during the entire design process. But the goodness or badness of an engineering design lies in the way in which it is used (Ambler, 2015). As Ambler stressed, the electric power built for cooling buildings can be used in a way that leads to global warming. Likewise, van de Poel (2009) mentions the arguments on engineering designs being value-neutral. The main assumption of these arguments is that the value of the design becomes important when end-users use or interact with it and thus, their means are determined by the extrinsic values rather than intrinsic values. On the other hand, van de Poel argued that engineering has values in itself as the value of engineering designs as a means to ends is based on intrinsic values. The question is whether engineers can anticipate the possible ways in which their designs can be used in the future and prevent it or regardless of how well they predict, whether they should take responsibility for the future use of their designs even if they do not have control over how it is used or maintained. This has been actually the topic of controversy. One of the important dimensions of engineering noted in the literature is to accept responsibility for engineers' own actions (Meyers et al., 2010). Gunn (2010) underlined that integrity, in that sense, is a vital virtue for the engineering discipline since integrity is not solely related to theoretical commitment to the ethical values but also actually put them into practice. To be more specific, integrity involves moral responsibility and the courage to stand up for their beliefs.

Engineering does not design solutions in the abstract or isolated from society, but rather they need to design the solution best satisfying the prevalent social conditions (Ambler, 2015). Zwart and Kores (2015) discussed that it is impossible to distinguish engineering design from its social context because the context in which designs are created is vital to its creation process. Solution ideas are tested based on value-laden criteria and those criteria or constraints could change in the course of time. For instance, sustainability was not a concern of engineers in the past; however, in recent years it became an important engineering criterion, especially after the impacts of engineering designs on the environment, have been realized to be irreversible. Therefore, engineering designs are contingent on the social and cultural context within which they are being created.

Vermaas (2015) highlighted the changing roles of engineers in the design process and in turn, in society. The scholar revealed three types of engineering designs that differ in terms of the role of engineering: user-driven, designer-guided, and designer-driven engineering designs. In the user-driven design, engineers design solutions for needs or problems determined by end-users while in the designer-guided design, engineers take a more active role in the problem definition phase and in turn, end-results. Engineers reframe or correct design problems proposed by end-users and integrate feedback from them in order to produce solutions that better address their needs or problems. In the designer-driven design, engineers take the role of an explorer of needs and problems. Engineers search and predict social trends, human behaviors, and user interactions with the potential product to identify their needs and desires. This type of design process could yield innovative designs that give society a new power. The political context is another influencer or sometimes determinant of engineering work (Wisnioski, 2015). In this sense, Meganck (2015) argued that having a moral responsibility to stand for what they believe requires “rebellious ethics”.

The Demarcation between Science and Engineering

“For engineers, in contrast to scientists, knowledge is not an end in itself or the central objective of their profession. Rather, it is... a means to a utilitarian end” (p. 6) (Vincenti, 1990, p. 6). The long-held traditional view of engineering holds that engineering applies existing knowledge about the natural world to produce practical solutions (Radder, 2009). Bunge, a philosopher of science and technology views that engineering is an applied science like many others. In that regard, scientists are viewed as *homo depictor* who explores and describes the natural world as it is while engineers are characterized as *homo faber (man the maker)* who are not interested in how the natural world works but rather concerned primarily with what can be built with the natural world (Kerr, 2016). On the other hand, this limited view of engineering has been challenged since engineers, and philosophers of engineering and technology unearthed that engineering has a distinct methodology, knowledge and epistemological and ontological commitments.

Scientists questioned what reality is while engineering addresses the questions of how the current situation could be transformed. For this reason, engineering aims for the transformation of a current situation by designing technological artifacts that are, then, used to solve problems while science seeks out understanding of natural phenomena (Goldman, 2017). The National Academy of Engineering [NAE] (2005) also made the distinction between science and engineering, focusing on their origins and current scopes:

> Science had its origins in the work of scholars supported by wealthy patrons and in the personal work of wealthy aristocrats who looked to the stars to understand the origins of the universe and life or who were intrigued to understand the natural physical, chemical, or biological world around them. Engineering had its origins in the trades, in the effort to make and implement something useful, first for military purposes and later for civil purposes (p. 20).

Such different goals give rise to different knowledge activities, methods, values, and rules, reasoning, and success criteria as well as standards for evaluation of "success" (Goldman, 2017). From this perspective, some argued that the difference lies in the ways of knowing, thinking, and doing (Figueiredo, 2014). Engineering knowledge is predominantly characterized by practical knowledge, knowing-how rather than knowing-that as in science (Sheppard et al., 2006). Engineering and science involve a different set of activities governed by their distinct logic. The scientific activities aiming at describing natural phenomena through general patterns necessitates abstraction and idealization whereas engineering activities aim to build concrete artifacts in real contexts where there are various uncertainties. Therefore, engineers encounter an epistemological problem of constructing a basis for decision making in circumstances where certainty is not possible.

Synthesis is a dominant activity in the design process rather than analysis as in science and design practices are governed by "holistic, contextual and integrated visions of the world" (Figueiredo, 2014, p., 23) as they integrate social needs, ethical values with technical knowledge. Therefore, engineering requires a generative mode of thinking rather than deductive thinking. Also, Cagan et al. (2005) used Wright brothers' design of powered airplane to indicate that cognitive activities that engineers engage in throughout the design process include cognitive problem-solving processes, the use of analogical reasoning to analyze previous designs and find the ideas or substructures that would be useful for the artifact design, relying on domain knowledge including both engineering and scientific knowledge and evaluating artifacts until the desired design is achieved. In this sense, the iterative analysis and synthesis are the essential ingredients of the design process. Also, Vincenti (1990) underlined creative thinking by using the analogy, visual thinking necessary for developing graphical representations, conceptual designs, models and prototypes and judgmental skills needed to evaluate viable solutions and make engineering decisions within a bounded social context. Other scholars also underlined the distinction between types of reasoning that are typically used in the science and engineering discipline (e.g., Hughes, 2009; Kroes, 2009). While theoretical reasoning guides the methods of science by means of which scientists understand the facts about the natural world, practical reasoning governs the engineering design process whereby engineers produce technologies and systems which transform that world (Hughes, 2009). Some also asserted that scientific reasoning involves inductive, deductive, or abductive reasoning whereas means-end reasoning plays a central role in designing. The means-end reasoning is a type of practical reasoning which is related to how to achieve an end using means (Kroes, 2009). In a similar vein, Gregory (1966) offered a distinction between scientific and engineering design practices in terms of the methodological approach that each discipline adopts:

> The scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things of value that do not yet exist. Science is analytic; the design is constructive (p. 6).

Also, Kroes (2012) proposed two distinct features of the engineering design method that demarcate the discipline of engineering from that of science as the decisional nature of engineering and a wide range of constraints under which engineers have to design. Engineers have to make various kinds of decisions to achieve "successful" design solutions. Besides, a variety of constraints such as economic, societal, ethical, safety, etc. structure design problems and ultimately, the outcome of the design activity. Therefore, engineers have to deal with and address those constraints during the design process. On the other hand, in the field of science, such constraints are not an issue for scientists since the nature of engineering and science problems have distinct characters.

Like science, engineering is also data-driven; however, unlike science, clients/society's needs are important components of the design process. Unlike science in which epistemic concerns are the core elements of the scientific activities, engineering work is defined by societal needs and requirements and engineering is concerned with improving the world and a method that enables them to succeed while minimizing the risk, cost, etc. Demands for the improvements of the world arise from industry, government, military, or society (Kerr, 2016).

Science and engineering communities share different values, norms, and rules; while scientists value knowing and understanding of the nature of things, engineers value doing and creating things (Vincenti, 1990). Engineering artifacts "is directed towards meeting a particular need, producing a practicable result and embodying a set of technological, economic, marketing, aesthetic, ecological, cultural and ethical values determined by its functional, commercial and social context'' (Archer, 1992, p. 8). Besides, the values that govern the scientific inquiry method are different than those of the engineering methods. To be more specific, scientists are concerned mainly with epistemic values including but not limited to explanatory power, simplicity, accuracy, and predictive power (Kroes, 2009). As Goldman (2017) argued, one of the fundamental distinctions between engineering and science is that engineering is identified by *contingency* as engineering design is limited to a particular social context within which it is intended to design while science is described by *necessity* given that the theories and laws of nature could not be created but only discovered:

> The problems that engage scientists are 'there', waiting to be recognized. Engineering problems, by contrast, are created by people who want to do something specific and are constrained in various ways, to a degree by what nature will allow, but primarily by highly contingent factors that, from a logical as well as a natural perspective, are arbitrary: time, money, markets, vested interests, and social, political and personal values.

Besides that, scientists are interested in certainty, abstractness, and universality and thus, aim to create objective knowledge as much as possible developed through observing natural phenomena in order for understanding how and why things happen. On the contrary, engineers deal with concreteness, particularity, and probability and base their work on rather mainly subjective knowledge developed through personal and past experiences (Bulleit et al., 2015). The contextual values (non-epistemic values), tough may be indispensable to avoid their impacts, may be conceived as a threat to the reliability and validity of theoretical knowledge in science (Rooney, 1992) whereas contextual values are crucial for "successful" engineering designs bearing in mind that engineering design problems are bounded within a specific context.

The Values of the Engineering Community

When it comes to the values of the engineering community, the most paramount one is ethical values. Engineering mainly deals with complex problems that lead to immense social, political, and economic consequences. Engineering design could give rise to great benefits but also, they may result in serious catastrophes. Therefore, engineers should always be obliged to take ethical values into considerations (Buch & Pederson, 2015).

Engineers are concerned with the efficiency of engineering practices. Engineers try to achieve to meet agreed-upon design criteria in an optimum manner (e.g., Mitcham & Schatzberg, 2009; Newberry, 2015a; Pitt, 2011). The functionality of engineering designs is also another core value at play during the design process (Bucciarelli, 1994). Vincenti (1990) and Bucciarelli (1994) identified the operational principles of engineering designs as the fundamental element of the design process. The operational principle highlights what the function of engineering design is or in short, how it works or behaves. The operational definition of design enables engineers to narrow down possible solutions and make judgments about the success or failure of the design (Nightingale, 2009; Vincenti, 1990). Besides, van de Poel (2009) stressed the functionality or utility as a core value of the discipline since every engineering design is designed for a particular use, and thus, designs should be built in a way that it fulfills a certain function. The values that engineers give priority during a design process may include, but not limited to and may vary and they include, but are not limited to context, health and safety issues, sustainability (Banse & Grunwald, 2009; Koehn, 1999), economy, time and satisfying customers' needs and desires (Banse & Grunwald, 2009; Jonassen et al., 2006), societal quality (Banse & Grunwald, 2009) as well as creativity, communication, problem-solving and learning (Anderson et al., 2010).

Values adopted by the engineering community could vary depending on cultural, social, political, and historical contexts (Poser, 2013). For instance, one of the primary concerns of engineers in America is to design "low-cost goods for mass consumption". On the other hand, engineers in a culture where the value of improving quality of life is viewed as important are most concerned with designing high-quality products (Anderson et al., 2010, p. 157). In another example provided by Downey et al. (2007) examined engineering cultures in three different countries, in France, Germany, and Japan. They reported that French engineers had more passion about serving the national public whereas German engineers were more sensitive to the social responsibility of engineers and Japanese engineers gave more priority to serving their company. Hence, historical, cultural, and political contexts could have a major role in determining the meta-level values of the engineering community.

Besides, apart from the core values including functionality, ethics, and economics, additional values could come into play during the design activity. The sources of those values may consist of the interests and desires of designers, customer/end-users, stakeholders, larger socio-technical systems in which the engineering design is created, will be embedded. For instance, an electric appliance that is intended to design should fit into the larger electrical system (Dorst & Overveld, 2009; van de Poel, 2009).

There is a controversy around whether the value of serving humanity is pervasive value in the engineering community or engineers should adopt the value-neutral approach in the literature (van de Poel, 2010). Some scholars argued that engineers need to design artifacts that are beneficial to society and the environment (e.g., Sheppard et al., 2006; van de Poel, 2010). One of the codes of ethics widely embraced in the United States is “using their knowledge and skill for the enhancement of human welfare” (ABET Code of Ethics of Engineers, 2003, p.1). Designing for the benefit of society is a shared value for many institutions and organizations worldwide (Newberry, 2015b). However, some focused on the universal ethical principles and claimed that engineers should avoid engaging in ethical questions regarding culturally specific issues related to the betterment of society. They advocated a more value-neutral morality for the engineering discipline (van de Poel, 2010).

In that sense, some scholars underlined differences between engineers' own moral values and ethical obligations. Moral values are more related to engineers' their own responsibilities, not necessarily related to the code of ethics of the engineering community. Davis (1998), for instance, while ethical codes are kind of obligations that tell engineers how they should act, moral values, or technical values such as efficiency and safety are just considerations that engineers should bear in their minds when designing or making decisions. Davis, then, claimed that failing to take public welfare into consideration as a primary value of engineering could not be seen as unethical even though engineers need to avoid causing harm to the public.

Engineers' identity is influenced by the values that they or their organizations have. Some engineers adopt values that their organization stands for and others generally working in smaller organizations to see the value in contributing to society. Even if it is not their main motivation or value, they would rather consider themselves as contributors to humanity or their organizations (Anderson et al., 2010).

The companies or organizations sometimes determine what value should be at play in the decision-making process. There are some incidents where engineers' values are in conflict with economic forces and organizational imperatives (Anderson et al., 2010). Therefore, the organizational culture has an immense impact on the values that engineers adopt. In this regard, some scholars argued that the majority of engineers work in private institutions that aim for financial growth rather than the benefit to humanity. For this reason, some think that engineering work is captive to financial interests, and consequently, this limits the ability of engineers to work for human interests (Newberry, 2015b).

Engineers sometimes define the needs that are to be built for. Innovative, or radical designs that are often called game-changers emerge from this kind of process (Vermaas, 2015;

Vincenti, 1990). To be more specific, many scholars claimed that the role of engineering has been deepened from technical problem-solving to concerning the needs and desires of end-users, organizations, and society. Engineers not only identify design problems but also reframe them and improve designs to produce better solutions for end-users. Especially after novel design methods were developed, engineers suggest and decide the need or problem to be addressed in the design process.

“Engineers are accountable to the public.” (Johnson, 2017, p. 92). Accountability as a social responsibility of engineers reflects the ethical obligations included in the code of ethics of the engineering discipline that stated engineers are accountable for the welfare, health, and safety of the general public (Johnson, 2017). Therefore, one of the social practices in engineering for accountability is that engineers have ethical obligations to report why and how failures in engineering designs take place. Another one is called whistleblowing which may be a moral or ethical responsibility of engineers to warn against actions or procedures which may create an unsafe situation. Engineers “blow the whistle” when they encounter an unethical act that is perpetrated by an employer or a client.

Michelfelder et al. (2017) underlined the problems societies increasingly experience today such as food insecurity and access to clean water and argued that with its power to transform our world, it is necessary to reimagine the future of the engineering discipline in such a way that they take an innovative and holistic approach to solve human problems and needs by considering social, political, economic, environmental and legal ramifications in order to better respond the complex and global problems.

Harris (2013) made an important distinction between the preventive and aspirational ethics of the engineering community which reflects the diverse views concerning the values of engineering in the literature. Preventive ethics, which are legally imperative, comprise of codes and rules for preventing harm to public safety and health. Engineers need to perform the design process in an anticipatory manner, detecting the causes of possible problems before they happen. On the other hand, aspirational ethics are related to the values of benefit society. Promoting public welfare, solving human problems, and enhancing the quality of their lives are idealistic values for the engineering discipline which are not imperative for engineers but rather personal commitments and should be given more emphasis in the discipline (Harris, 2013). Harris identified four virtues for this type of ethics including aspirations to professional excellence, care for nature, sensitivity to the effects of engineering designs on society, and benevolence. Similarly, Dias (2019) also advocated that engineering should be an instrument of humanization and transformation.

Newberry (2016) suggested a four-level hierarchy of the values of the engineering community. The values vary hierarchically from specific engineering contexts to larger engineering communities. The values at the meta-level are overarching values that can be applied to most of the engineering work. For instance, designing artifacts and technologies that do not pose a threat to public health and safety is paramount to the engineering discipline overall. Engineers should take into consideration the safety codes in everything they do. Designing for humanity could also be regarded as a core value of the engineering communities. Many engineers share this value but as stated before, it would be unrealistic to call it a universal value that all engineers and organizations adopt. Sustainability especially in recent years has become of greatest importance in the discipline but still, it is not applicable for all engineering contexts. As Newberry noted, it is worth mentioning that these meta-level values could change and vary from time to time, culture to culture or political systems to political systems, and so on. The values at the macro-level encompass the values of engineering organizations and/or companies. A company could embrace meta-level values such as sustainability or serving to the public or humanity as their own core values. Each organization may have unique values that also represent their missions (Davis, 1998). For instance, some organizations are customer-oriented which means that their prime concern is their customers' values. On the other hand, in engineer-oriented organizations, the most paramount value at play in decision-making is the quality of the artifacts. The quality of the products is generally determined by the organization itself, not by customers. Also, some organizations or engineering firms put high value in profits or economic growth. The values at the micro-level involve the values effective in specific engineering works. These values could be end-users or engineers' personal values such as efficiency, standardization, reliability, effectiveness, etc. At the meso-level, the values that come into play as describing the functionality of the product being intended to design. Innovative ideas, the effectiveness of the design, efficiency, sustainability, etc. could become paramount to a specific design process. Several values could gain importance at different levels; however, the important distinction is that at the micro-and meso-level, the values adopted are specific to a particular design solution while at the macro level values are shared by the organizations and engineers work within these organizations and the values at the meta-level are applicable to almost all engineering communities such as ethical values.

Another distinction was made regarding the values of the engineering designs by van de Poel (2009). Utility value engineering designs are being used for some end. On the other hand, instrumental value is related to the design being used for a good end. However, the instrumental value of an engineering design process could be good or bad depending on the objective for which it is being utilized or in other words, depending on the intentions of how to use it. But at the same time, every engineering design has its own intrinsic value given that it is designed with a certain function in the mind of engineers. It is, therefore, not only the extrinsic values that end-users ascribe to the design determine on what purpose they will be used. The second value the scholar highlighted was economic value. The economic value is related to creating products that are affordable and cost-effective. Engineers and/or organizations often attempt to make the same product more economical for consumers/customers. Moral value is considered as another core value of engineering. Every engineering design, intentional or unintentional, has certain effects that may create values or disvalues. In that sense, engineering designs can be examined with respect to the value or disvalue they generate through their use and their side-effects. The side-effects of engineering designs are usually not intentional. Engineers and end-users do not aim car accidents to take place; however, designers should always take the possible side effects of their design into consideration when designing. Lastly, cultural and aesthetic values, beyond instrumental or utility value, could be regarded as essential values for engineering designs.

van de Poel (2013) elucidated how values are translated into design requirements that govern the design process. Abstract values are translated into end-norms which are attributes, functions, properties, or features that the product should have. The end-norms are sometimes conceived as the objectives of the design process established for integrating values in the design process. Then, the end norms are translated into specifications by providing more detailed information concerning what, when, and how actions should be taken and what and how directions should be followed.

Learning from Failure

Given that engineering designs are created to be used, feedback from the use of and experience with the design is crucial for further design practices (Vincenti, 1990). The feedback is not only obtained from successes but also from design failures to inform future designs. Even Petroski (2018) once stated “things that succeed teach us little beyond the fact that they have been successful; things that fail provide incontrovertible evidence that the limits of design have been exceeded.” (p., 114). The post-failure analysis, in this sense, is vital to develop new knowledge in the engineering discipline that minimizes future engineering failures. Petroski, in his book “Success through Failure”, supported the claim that engineers learn from failures more than design successes and pointed out the paradoxical nature of engineering. Design failures are to some extent inevitable in engineering, thereby requiring engineers to actively detect and isolate the possible causes of failures and use ways to avoid them. The success of a design is determined by how well designers predict and prevent failures. “Failure is, therefore, can be regarded as “a unifying principle” of the engineering design” (Petroski, 2018; p. 2). On the other hand, engineers designing new engineering artifacts, systems, or technologies benefit most from learned lessons from the failures of existing designs. For instance, the failures made in the design of Titanic added much more to the knowledge of the engineering community leading to safer ocean liners. Therefore, functional failures and anomalies are one of the important sources of the development of engineering knowledge (Vincenti, 1990).

Chapter 3

Methodology

The methods employed for the purpose of ascertaining which epistemic aspects of engineering should be an integral part of K-12 education were the three-round Delphi technique, and focus group interview.

The Research Paradigm of the Mixed Methods Research

It is important to specify what research paradigm with its epistemological and ontological presuppositions was used to guide the study. In this study, quantitative and qualitative methods of research were employed to answer the research questions. Therefore, the mixed methodology which “integrates two forms of data and their results, and frames [both] procedures into theory and philosophy” was employed in this study (Creswell & Clark, 2017, p. 5). The qualitative component of the research design consisted of experts’ opinions on the epistemic aspects of engineering and the aspects relevant to K-12 science and engineering education. The quantitative component employed the descriptive statistics to analyze the relative importance of each epistemic aspect of engineering that emerged from the Delphi study and to measure the agreement level for consensus.

This was a mixed methodology study, which combines constructivist and pragmatist worldviews. In other words, this study was guided by dialectical pluralism which is defined as an epistemology that requires combining multiple epistemological perspectives (Johnson, 2012). Therefore, the constructivist approach allowed the researcher to uncover and bring multiple perspectives together while the pragmatist approach enabled the researcher to evaluate those perspectives to find the most useful knowledge for real-life practices.

Denzin and Lincoln (2017) described qualitative research as “a situated activity [that consists of] an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them” (p. 43). Denzin and Lincoln (2017) argued that the research paradigm that reflects the researcher’s worldviews comprises the ethical, epistemological, ontological, and methodological assumptions. Denzin and Lincoln, in this sense, proposed four competing research paradigms including positivist and postpositivist, critical, feminist, constructivist-interpretive, and participatory-postmodern post-structural. (Guba, 1990; Lincoln & Guba, 2013).

This study adopted the constructivist-interpretive paradigm to unearth essential epistemic aspects of engineering. Lincoln and Guba (2013) argued that constructivist research paradigm presumes a relativist ontology which underlines that there are multiple realities constructed by people in particular contextual and historical settings, a subjective epistemology which assumes that the researcher and the respondent co-build the knowledge and a hermeneutical/dialectical methodology which aims at gathering multiple constructions of reality which produce better interpretations of meaning (hermeneutics) that are compared and contrasted through dialogue/argumentation method of dialectics.

The interpretative researcher attempts to explore the meaning as it is based on the subjective experiences and understandings of respondents. Therefore, there could be a multiplicity of meaning at the end of the process of inquiry. Qualitative positivist researchers consider this as a threat and use inter-rater reliability measures to exclude multiple interpretations. On the other hand, interpretative researchers embrace multiple meanings and realities. Also, the interpretative researcher’s focus is on the process of meaning-making within a specific context. From this perspective, rather than generalizability, contextuality is what matters for the interpretive researcher to guide the research practices (Schwartz-Shea & Yanow, 2013).

On the other hand, pragmatism which is mostly associated with the mixed methods, focuses on the "what works, using diverse approaches and valuing both objective and subjective knowledge" (Creswell & Clark, 2017, p. 39). Specifically, the main focus is on the result of the study which informs the problem under investigation. Hence, the purpose of the current study was to unpack multiple meanings with regard to essential features of engineering and then, use the consensus-building method in order to produce the most important and useful knowledge for educational practices.

Delphi Study

A comprehensive set of epistemic aspects of engineering has yet to be clearly identified. Establishing the key epistemic aspects of engineering that K-12 students should ideally learn requires input from experts in the field of science, engineering, and education. As one of the best research methods for building a knowledge base in areas that have no or incomplete foundation in the literature (e.g., Mohr & Shelton, 2017; Skulmoski et al., 2007; Wicklein et al., 2009), the Delphi method was employed in this study.

The Delphi method was originally developed by the researchers at Rand Corporation to make informed decisions in policy-making. Over the last three decades, Delphi method has been performed across social sciences to evaluate teaching practices (e.g., Fogo, 2014; Jordens & Zepke, 2017; Kloser, 2014), to develop conceptual models for curriculum (e.g., Cunningham & Kelly, 2017; Rossouw et al., 2011), and to determine objectives for education (e.g., Blanco-López et al., 2015; Rupert & Duncan, 2017). Delphi methodology allows researchers to elicit the views of qualified experts on the presented issue when there are uncertainty and limited knowledge base in previous research. This methodology enables experts who may be geographically dispersed to share their opinions, exchange their views and judgments, and eventually to build a knowledge base through a systematic and iterative consensus-building process.

In Delphi studies, different research methodologies including quantitative, qualitative, and mixed methods could be used based on the purpose of the study and the type of data sources. In this study, a mixed-methodology which incorporates constructivist and pragmatic paradigms was employed. The main aim of this Delphi study was to identify various important epistemic aspects by using open-ended questions and interviews. And additional aim was to determine the most important epistemic aspects of engineering through ranking techniques by using descriptive statistics.

At the first analysis, the ontological and epistemological assumptions underpinning the Delphi study seem to favor the positivist research paradigm which presupposes that the researcher is the objective observer who does not get involved in the process of inquiry. This objectivist stance is supported by the quantitative data collection and analyses alone to measure the consensus. Relying on the data from experts' opinions presupposes realist ontology which construes the single reality on which experts reach an agreement. Also, the reductionist approach taken to identify the model underlies the positivist approach. However, several scholars claimed that the Delphi method includes both qualitative and quantitative approaches. Therefore, the assumptions underlying this technique aligns with the constructivist paradigm (Hanafin, 2004).

The Delphi method is concerned with the opinions and perceptions of experts to approach a decision. Specifically, this method enables the way in which each expert who has preferably different backgrounds and experiences contributes to the creation of knowledge. Such an approach is consistent with the constructivist interpretive paradigm focusing on subjective human experiences and contextual meaning of knowledge. The researcher, in this process, is far from being an objective observer, but rather takes part in the knowledge creation process together with the experts because the researcher is the one who interprets the data through an inductive approach. That is to say, the researcher and the experts co-construct the knowledge. Also, the Delphi method is used not only to unearth multiple realities and perspectives at each phase but also to gather these diverse perspectives together as moving to the next phases. Also, the purposes of this study were consistent with the pragmatic approach which focuses on the consensus on the most important epistemic aspects of engineering and the aspects relevant to K-12 engineering education and seeks a consensus. Hence, the mixed method Delphi technique was considered an appropriate method for this study since it enables the researcher to obtain all possible perspectives together from the ones who have first-hand knowledge and practical experience and consequently, reach a consensus.

Previous studies adopting the Delphi method approach consulted experts' opinions from a wide range of professional fields including researchers, educators and practitioners to collect multidisciplinary data to build a consensus around important ideas (e.g., Osborne et al., 2003; Rossouw et al., 2011) In science education context, Osborne et al. (2003), for instance, employed three-round Delphi method to determine what important ideas about science should be included in science teaching and learning. They formed an expert panel including scientists, science educators, science education researchers, historians, philosophers, and sociologists of science. Likewise, Rossouw et al. (2011) attempted to gather opinions of experts from the fields of philosophy/history of technology, technology education and engineering education to determine what key concepts should be integrated in engineering and technology education and eventually to contribute to the creation of the technological literacy goals. In this study, the Delphi panelists who were researchers in the field of philosophy and history of engineering/technology, engineering/science education/researchers, and practicing engineers were selected.

Okoli and Pawlowski (2004) identified two types of Delphi study for educational purposes: concept/framework development and forecasting/issue identification. The aim of the concept/framework Delphi method is to determine the important and key concepts for curriculum development. In the present study, the concept/framework Delphi methodology is used to determine the epistemic aspects of engineering which could inform classroom implications, curriculum/standards designers, and educators.

Delphi method has several distinct features from other group data collection methods including (a) anonymous group interaction and feedbacks: participants' answers are kept anonymous form the group which minimizes the potential adverse effect of group dynamics such as manipulation or dominant behaviors; (b) cost-effective and easy access to a sample of experts: with the developments in online technology, the data could be collected with (c) controlled feedback: participants are given the opportunity to provide additional comments, revise and clarify their prior responses through multiple iteration processes.

Before employing the Delphi method, it is necessary to examine the drawbacks of this method along with its methodological advantages. Several methodological difficulties have been voiced associated with the Delphi process (e.g., Hsu & Sandford, 2007; Osborne et al., 2003). Those include the length of the process and the risk of sample saturation. However, the most prominent drawback of Delphi methodology is the influence of the researcher's views on expert panels' opinions. Several studies argued that the iterative nature of the Delphi process could lead the researcher to shape the participants' opinions rather than objectively collect data. On the other hand, in most qualitative research studies, the interpretative researcher presupposes that the meaning and so the knowledge is jointly constructed by the research participant and the researcher (Denzin &Lincoln, 2017), let alone influencing the respondents' views. This subjective nature of qualitative research should not be understood as a threat to the trustworthiness of the study. Instead of calculating inter-rater reliability as positivist researchers do, the interpreter qualitative researcher should describe the way of data collection, analysis of data, and researchers' background and presumptions as clearly as possible to establish the trustworthiness of the study (Schwartz-Shea & Yanow, 2013).

The Delphi Process

Even though several scholars contended that consensus among the expert group can generally be reached after three iterations (e.g., Hsu & Sandford, 2007), theoretically, the iteration process could be performed until a consensus is reached. In this study, the overall consensus was achieved at the end of the third round, thereby no need for another iteration. Therefore, the current study gathered data over three rounds. Before the Delphi study began, an open-ended questionnaire including four questions concerning the features of engineering was developed to be used in the first round. To confirm whether the questions were specific and precise, and avoid any ambiguity in questions and their interpretations, the initial version of open-ended questions were critically examined and reviewed by four experts in the fields of science education, educational technology, and engineering. The experts were asked to provide their opinions and suggestions with respect to the clarity of the open-ended questions and their relevance to the expert panel of the Delphi study.

Panelist Selection

Delphi method does not seek to have generalizable samples but rather inquires input from purposive samples of people who hold expertise on the issue discussed. As Hsu and Sandford (2007) pointed out, there are no agreed-upon criteria to define an expert in a given area and select expert panelists in the existing literature. However, it is generally accepted by the Delphi researchers that the individuals who are capable of and willing to provide beneficial input and have training and experience in the interested area, be selected as expert panelists (Hsu & Sandford, 2007; Osborne et al., 2003). Another important criterion is the use of interdisciplinary panels which could potentially provide heterogeneous viewpoints (Blanco- López et al., 2015). Bearing these suggestions in mind, the panelist selection, in this study, was made based on the criteria of maximizing expertise and encompassing a broad range of experts. To be more specific, individuals having at least Bachelor's degree in a given area (engineering, engineering education, science education) and at least three years of experience in the field were chosen.

The invitation letter for the Delphi study was sent to professional engineer communities, and national science and engineering education email lists. The letter explained the purpose of the study as identifying the important features of engineering discipline and the procedure of the Delphi study. Besides, a screening questionnaire was sent along with the invitation letter. The questionnaire was designed to obtain demographic data including the questions of (a) affiliation or organization; (b) position/job title; (c) area of expertise including engineering education, philosophy of engineering/technology, history of engineering/technology, practicing engineer in industry, philosophy of science, and science and engineering education (d) years of experiences that they have in the given field and (e) detailed explanation for qualifications and experiences in the given field. The consent form together with the information with respect to confidentiality was also included in the screening questionnaire.

All participants were assured explicitly of their anonymity. Also, they were kept unaware of the identity of other Delphi panelists so that their opinions were not influenced by the status and responses of other panel members (Brady et al., 2015). Even though there are no established criteria concerning the ideal number of experts to be recruited in a Delphi study, the Delphi literature generally suggests that approximately 15-25 experts or more ensure a heterogeneous panel (Hsu & Sandford, 2007). Further, it was suggested that the Delphi studies including more than 30 experts rarely provide additional new information (e.g., Clayton, 1997; Sekayi & Kennedy, 2017). In this study, a total of 51 participants initially responded to the screening questionnaire and only 30 of the 51 participants participated in Round 1.

Characteristics of the Delphi Panelists. A total of 30 participants from different disciplines agreed to participate in Round 1 of the study. The sample of the Delphi study for round 1 was included as follows:

(1) Engineering Education (EE) (n=11). This group included engineering/science educators in higher education working in different universities

(2) Engineering Education/Philosophy and History of Engineering/Technology (EEP) (n=8). This group of experts comprised of engineering/science educators in higher education, plus they were researchers in the area of philosophy of engineering/technology

(3) Engineering Education/Practicing Engineers (EEPE) (n=8). This group included engineering/science educators in higher education and they had worked previously in the industry as a practicing engineer.

(4) Practicing Engineers in Industry (PE) (3): This group of engineers consisted of practicing engineers in different industries

However, fewer participants completed the second and third round questionnaire. The 19 of the 30 experts participated in the second round and the final sample was 16 experts in the third and last round (Table 3.1). As regards their qualifications and positions, the majority of participants had a P.D. degree (73.33%). In regard to their positions, 26.67% were professors, 10% were associate professors, 30 % were assistant professors, and 36.67 % of the participants were either practicing engineers or previously worked as a professional engineer in the industry. The participant experts were diverse in regard to their geographical locations being based in Turkey, Canada, Puerto Rico but mainly the United States.

Table 3.1

The characteristics of the panel member of the Delphi study

Expert Code		Region	Gender	Professional Category	Education	Area of Study	Relevant work experience (years)	Participation
EE	EE1	USA	Female	Director	Ph.D. in Education	Outreach Programs and Women in Engineering	3+	Three Rounds/ Interview
	EE2	Canada	Male	Associate Professor	Ph.D. in Mechanical Engineering	Mechanical Engineering	15+	Three Rounds/Interview
	EE3	USA	Male	Associate Professor	Ph.D. in Civil Engineering	Civil and Environmental Engineering	15+	Round 1 and Round 2 /Interview
	EE4	USA	Male	Associate Professor	Ph.D. in Engineering Education	Mechanical Engineering	6-10	Three Rounds/Interview
	EE5	USA	Female	Assistant Professor	Ph.D. in Chemical Engineering	Chemical Engineering	3-5	Three Rounds/ Interview
	EE6	Canada	Female	Lecturer	Ph.D. in Civil Engineering	Civil Engineering	3-5	Round 1
	EE7	USA	Female	Science/Engineering Educator	M.S. in Science Education	Science/Engineering Teacher Education	3-5	Three Rounds
	EE8	USA	Female	Science/Engineering Educator	M.S. in Science Education	Science/Engineering Teacher Education	6-10	Round 1
	EE9	USA	Male	Interim Chair, Professor	Ph.D. in Vocational	Technology/Design Teacher Educator	10-15	Round 1

					and Industrial Education			
	EE10	Puerto Rico	Female	Professor	Ph.D. in Mechanical Engineering	Mechanical Engineering	6-10	Round 1
	EE11	USA	Female	Professor and Department Chair	Ph.D. in Civil Engineering	Environmental and Civil Engineering	10-15	Round 1/ Interview
EEP	EEP1	USA	Male	Professor	Ph.D. in Engineering Mechanics	Mechanical Engineering Aerospace Engineering	15+	Three Rounds/Interview
	EEP2	Turkey	Male	Professor	Ph.D. in Civil Engineering	Civil Engineering	15+	Round 1/Interview
	EEP3	USA	Female	Assistant Professor	Ph.D. in Computer Information Systems	Engineering/ Information Security and Assurance (ISA)	15+	Three Rounds/ Interview
	EEP4	USA	Male	Professor	Ph.D. in Engineering Science	Civil and Environmental Engineering	15+	Three Rounds/Interview
	EEP5	USA	Female	Assistant Teaching Professor	M.S. in Electrical Engineering	Electrical Engineering/ Engineering Design	6-10	Round 1
	EEP6	USA	Male	Assistant Professor	Ph.D. in Science Education	STEM Education	3-5	Three Rounds/Interview
	EEP7	USA	Male	Professor	Ph.D. in Philosophy	Philosophy of Technology, Engineering, and STS	15+	Three Rounds

	EEP8	USA	Male	Teacher	Bachelor’s in Industrial Technology	Engineering and Technology	6-10	Three Rounds
EEPE	EEPE1	USA	Male	Assistant Professor/ Practicing Engineer	Ph.D. in Mechanical Engineering	Aeronautical Engineering	15+	Interview
	EEPE2	USA	Male	Teacher/ Practicing Engineer	B.S. in Mechanical Engineering	Science Education, Engineering Education,	15+	Three Rounds/Interview
	EEPE3	USA	Female	Assistant Professor/ Civil and Structural Engineer	Ph.D. in Engineering	Construction Management Technology/	15+	Round 1 and 2
	EEPE4	USA	Female	Adjunct Professor and Research Engineer	Ph.D. in Mechanical Engineering	Mechanical Engineering	15+	Three Rounds
	EEPE5	USA	Male	Professor/Environmental Engineer	Ph.D. in Sanitary Engineering	Environmental Engineer, Civil Engineering	15+	Round 1
	EEPE6	USA	Female	Science and Engineering Educator/ Mechanical/Industrial Engineering	M.S. in Physics and Mathematics	Science/Engineering Teacher Education	3-5	Three Rounds
	EEPE7	USA	Female	Adjunct Professor/ Practicing Engineer	Ph.D. in Physics	Science Educator	15+	Round 1 and Interview

	EEPE8	USA	Female	Assistant Teaching Professor/Mechanical Engineer	Ph.D. in Mechanical Engineering	Mechanical Engineering	15+	Three Rounds/Interview
PE	PE1	USA	Male	Practicing Engineer	Ph.D. in Electrical Engineering	Computer Engineer	10-15	Three Rounds/Interview
	PE2	USA	Female	Practicing Engineer	B.S. in Electrical Engineering	Electrical Engineer	3-5	Round 1 and Round 2
	PE3	USA	Female	Practicing Engineer	M.S. in Engineering Technology & Information Technology.	Systems Engineer	10-15	Round 1

Note: EE: Engineering Education
EEP: Engineering Education/Philosophy/History of Engineering/Technology
EEPE: Engineering Education/Practicing Engineer in Industry
PE: Practicing Engineer in Industry

The three-round Delphi method includes three phases including concept discovery (first round), concept prioritization (second round), and concept rating (third round) as follows.

Round 1 (Concept Discovery). The first round of the study, begun in December 2019, included an open-ended questionnaire in which the panel members were asked to express their ideas about the key aspects of the engineering discipline. The online questionnaire conducted via Qualtrics^{TM} survey software was sent to the participants electronically. The questionnaire posed the following questions: (a) what, in your opinion, is the nature of engineering knowledge that engineers use when designing engineering solutions? (b) what, in your opinion, are the stages of the engineering design process? (c) what, in your opinion, are the key features of the engineering design? (d) what, in your opinion, are the fundamental norms, rules, and values of the engineering community? The participants were also invited to provide a clear description of each idea and explain their reasoning.

The 30 participants provided responses to all four questions in Round 1. In this round, the participants were invited to generate ideas, and little guidance was provided concerning what content of responses was expected. Following the questionnaire, semi-structured interviews were conducted with seventeen expert panelists (56.67%) to elaborate on and clarify their written responses to each question (see Table 3.1). During the interview sessions, several additional questions were asked to further identify the important epistemic aspects of engineering including the relationship between engineering and society, skills that engineers should have, and additional features that they think are important for a K-12 student to learn.

Qualitative Data Analysis. The qualitative analyses continued until the point when theoretical codes were developed. In the first round, the panel members' written responses and interview data were analyzed through using an inductive approach and coded reflexively and iteratively. In the second and third round, experts' comments with respect to the themes were qualitatively analyzed. The themes obtained from the Delphi study were discussed with a group of K-12 science and engineering educators during a focus group meeting. The data drawn from the Delphi study and focus group meeting were further analyzed in order to analyze the relationships among the themes which led to the construction of the theoretical codes (see the following section for more details). The MAXQDA qualitative data software program was used in order to perform the initial thematic analysis and improve the accuracy of the qualitative analysis.

In this study, the aspects of constructivist grounded theory (Charmaz, 2006) were integrated into the data analysis procedure. Instead of making a priori assumptions regarding epistemic aspects of engineering, this methodology enabled the researcher to learn from "experts" about the epistemic aspects that were most pertinent to their professional knowledge and experiences. The grounded theory was broadly described as a "general methodology for developing a theory that is grounded in data systematically gathered and analyzed" (Strauss & Corbin, 1994, p. 158). Schreiber and Stern (2001) stated that grounded theory is "useful for research in areas that have not previously been studied where there are major gaps in our understanding, and where a new perspective might be beneficial" (p. 57). In grounded theory method, data collection and analysis are performed concurrently so that they reciprocally inform each other throughout the study. This enabled the researcher to explore the emerging findings and the following data collection was done to validate, broaden, or rebut the emerging theory.

Grounded theory was originally proposed by Glaser and Strauss (1967) to "bridge the gap between the theoretically uninformed empirical research and empirically uninformed theory as a response to extreme empiricism" (Goulding, 1998, p. 51). Glaser and Strauss later diverged in their views about the precise nature of methodology due to their different ontological and philosophical assumptions about the nature of reality and knowledge. Glaser refused to take a philosophical stance with regard to the grounded theory methodology. In his article, he discussed the “quest for an ontology and epistemology for justifying GT [grounded theory] is not necessary” (Glaser, 2005, p. 5). However, his views about pure induction are aligned with the positivist approach. Specifically, the classical grounded theory advocated by Glaser assumes that the researcher is an objective observer and inquirer who discovers the theory grounded in data by setting aside their presumptions and previous experiences (objectivist approach), and the classic grounded theory researcher tries to describe the reality that already exists within the field (realist approach) (Glaser, 1978). In line with that, several classic grounded theory researchers do not conduct the literature review before carrying out the research to avoid any kind of biases and rely only on the data collected from interviews and/or observations and aim at making generalizations based on the objective data (Charmaz, 2006). Strauss later collaborated with Corbin to propose further guidelines on how to carry out grounded theory research. Their philosophical approach to grounded theory method implies a post-positivist realist approach. Strauss and Corbin (1998) challenged the traditional positivist perspective by emphasizing the inevitable influence of researchers’ presumptions and experiences on the inquiry process. However, in their study, they argued that “theory derived from data is more likely to resemble 'reality' than is a theory derived from putting together a series of concepts based on experience or solely through speculation” (p. 12). From this perspective, they suggested that the researcher take an objectivist stance to approach the reality that exists independent of our experiences and actions (realist approach). Therefore, they offered a systematic approach to reduce the researcher’s bias and maximize objectivity. Also, unlike Glaser (1998) emphasized the beneficial aspects of an early literature review.

Charmaz (2006), a former student of Glaser and Strauss, offered a constructivist and interpretive approach to the grounded theory which rests on a relativist ontology and subjective epistemology. In contrast to Glaser and Strauss, Charmaz contended that “neither data nor theories are discovered” (p. 10). Rather, the data and theories are constructed by the researcher as a consequence of their interactions between the responders and emerging analyses. As a result, there may be multiple and sometimes competing perspectives of reality.

Similar to Strauss and Corbin, Charmaz (2006) acknowledged that researchers’ worldviews, presuppositions, and background knowledge inevitably affect how they analyze and interpret the data. However, unlike previous authors of the grounded theory, Charmaz offers a different approach to handle the researcher effect. She asserted that instead of trying to set aside or control their presumptions and preconceptions, constructivist grounded theorists should have reflexivity and explain their presumptions clearly during the data collection and analysis. Therefore, Charmaz suggested that researchers’ previous experiences and existing knowledge (e.g., current literature on the subject under study) be used to challenge the different points of view or bring new perspectives.

The data in this study were systematically analyzed following the procedures of the constructivist grounded theory method. The preliminary analyses were performed continuously during the data collection process. The constructivist grounded theory includes two main coding phases: initial and focused coding. During the initial coding, it is essential “to remain open to all possible theoretical directions indicated by [the] readings of the data” (Charmaz, 2006, p. 47). In contrast to Glaser’s approach which assumes that researchers perform initial coding with no prior conceptions in mind, Charmaz underlined the distinction between being open and empty-minded. It is important to be open-minded during the initial coding; however, researchers should acknowledge their preconceived ideas or theories (Charmaz, 2006). The initial phase includes labeling "each word, line, or segment of the data." (Charmaz, 2006, p. 47) through word by word, line by line, or incident by incident reading and coding. Therefore, after the expert panel's responses to the three questions including written responses and interview transcripts were imported to MAXQDA statistical program, responses were read multiple times including close word by word and line by line analysis and then, the initial list of emerging themes related the epistemic aspects of engineering were developed using the constant comparative method.

In the second phase, focused coding is conducted to "synthesize and explain larger segments of data" (Charmaz, 2006, p. 57). During this phase, related codes were categorized and the relationships between codes were explored to generate larger analytical categories. In this phase, if a theme was proposed by only one expert panel member, the themes were labeled and their summary statements were structured around their description of the themes. If themes or closely related themes were suggested by more than one panel members, they were labeled and the summary statements of these themes were created including all aspects of their descriptions. These analyses initially twenty-eight themes with respect to the epistemic aspects of engineering.

A questionnaire including each emergent theme with a summary created for each theme in the light of the panel members' statements and the statements provided by the panel members was developed for the second round. The supporting statements were anonymously presented as the typical supporting statements. Figure 3.1 indicates the summary coupled with supporting statements for an emerging epistemic aspect-Communication.

1-Communication:
Summary: Communicating solutions during and after the engineering design process is an integral part of the engineering discipline. Engineers need to communicate effectively with multiple individuals, teams and/or companies using different modes of expression including standard formats for engineering drawings and schematics, standard modes of writing and reporting technical information, etc. Communication is also important to understand the needs and problems in society and ultimately to serve humanity.

Typical Supporting Statements:
(1) Engineering projects often cut across not only multiple individuals, but multiple teams, multiple divisions of a company, or even multiple companies involving contractors, subcontractors, and vendors. Therefore, communication, coordination, and logistics within and between organizations are often crucial to the success of engineering projects.
(2) Communicating the solution: The engineering must be able to communicate technically analysis, the solution, its requirements, and specifications, how it was optimized, and how it should be tested, implemented, and monitored. Also, Engineers are tasked with developing for humanity. In this case, the only way to understand the experiences and desires of a person outside of your daily life is to listen and work hard to understand their situation.

Figure 3.1 One theme from Round 1 along with typical supporting statements

Throughout the Delphi study, theoretical codes were not created even though several more abstract concepts emerged. In other words, the focused coding continued throughout the Delphi study since the themes were reorganized, revised, merged, or excluded from the list of the themes based on the panel members' comments. In this respect, Howard (2018) which proposed the integration of grounded theory methodology into the Delphi study, suggested that the rankings in the Delphi study could help researchers in developing theoretical concepts. Therefore, after examining the relative importance of epistemic aspects of engineering and experts' comments, I moved to theoretical coding where more abstract concepts were created.

Second Round (Concept Prioritization). The panel members were provided the list with representative anonymous supporting statements for each epistemic aspect collected from panel members in the first round. Then, they were asked to review and decide which aspects better represent engineering activities. They were invited to rate the importance of each theme to the engineering discipline on a 5-point Likert scale, with 1 indicating the lowest degree of importance and 5 the highest degree of importance. Also, they were given an opportunity to provide justifications for their rating and express their opinions on the supporting statements; how accurately the title and supporting statements represent their opinions. In this round, 19 of the 30 panel members took part in the study.

The SPSS statistical program version 26.0 was used to calculate the means, modes, and standard deviations for each theme based on the rating provided on the 5-point scale. The mean rating of the 28 themes ranged from 3.84 to 4.84. The mean values of twenty-six themes were 4 and above which indicates the themes were regarded by most panel members as being important or very important. Of these twenty-six themes, twenty-two themes indicated a standard deviation of less than one, demonstrating a high degree of consensus for these epistemic aspects of engineering.

The comments provided by the panel members included (a) suggested revisions for the summary statements of the themes; (b) further supporting statements; (c) further clarification for the themes; (d) suggested excluding of the themes due to being not applicable to all fields in engineering; (e) suggested merging the themes due to overlapping, interrelated ideas; (f) suggested splitting of the themes and (g) suggested inclusion of new themes. In the light of the comments, the summary statements of several themes were modified and revised, and two themes were split into two themes. Most of the comments were taken into consideration in the third-round questionnaire.

Because there is no clear guidance in related literature regarding the minimum agreement level for consensus, the researcher determined the appropriate cut score for consensus. The Delphi researchers indicated that when a lengthy and detailed questionnaire was presented, the responses toward the end of the final rounds became uninformative (Osborne et al., 2003). Therefore, only the themes with a mean rating exceeding 4 and standard deviation being less than one were retained, reducing the number of themes in this round to twenty-four themes. Additionally, the themes of *Identification of Design Specifications and Requirements,* and *Honoring intellectual property* were given a separate category based on the suggested revisions. Therefore, a total of twenty-six themes were presented to the participant experts in the third and last round.

Third Round (Concept Rating). In the third round, 16 of the 19 participants from Round 2 completed the questionnaire. The panel members were presented with a final revised list and representative anonymous suggested revision statements derived from the previous round. In this round, the participants were also presented with the mean and standard deviation calculations of the ratings for each theme. Figure 3.2 indicates the summary coupled with a suggested revision for an epistemic aspect-Multiple Solutions. The participants were invited to rate each theme again on a 5-point scale based on its importance relative to the other themes. Also, participants were again given a chance to revise their responses.

4-Multiple Solutions (M= 4.2, SD= .78):

Summary: There is no one single solution to a problem in designing. There may be multiple design solutions to a design problem, each with unique pros/cons. Depending on the customers'/consumers' preferences, criteria, and design constraints, the optimal solution could vary. However, it is important to acknowledge that engineers work under time constraints that come with their problem, so it does not benefit the engineer to invest too much time testing all solutions.

Suggested Revision:

(1) Yes, there are multiple solutions, but it is also important for an engineer to understand the time constraint that comes with their problem. It does benefit an engineer to understand there are multiple, workable solutions, but it does not benefit the engineer to waste time testing all solutions.

Figure 3.2 Revised version of Multiple Solution theme from Round 2 along with a suggested revision

The same consensus criteria (mean> 4 and standard deviation< 1) was used for Round 3. To provide reliability, consistency of responses between Delphi rounds which is defined as stability was also taken into consideration. Similar to consensus criteria, there are no clear guidelines in the literature with respect to how to measure stability. Therefore, this study followed the criterion that previous Delphi studies in science education literature utilized. In this regard, based on those studies, stability was considered as a change of one-third or less in the ratings of the expert panel members between Round 2 and Round 3 (e.g., Blanco-Lopez et al., 2015; Osborne et al., 2003). In light of the stability criterion, this study yielded twenty-three themes at the end of the third and last round.

Focus Group Technique

After the data collection and initial data analysis of the Delphi study were completed, an online video-recorded focus group interview was conducted. A small group of experts including K-12 science and engineering educators who had experience in engineering education research was selected and invited to review the results of the Delphi study and express their opinions on the importance of epistemic aspects of engineering for K-12 science and engineering education and grade-band progression of the aspect. A total of six participants in the field of K-12 science and engineering education attended the focus group meeting. The characteristics of the participants were shown in Table 3.2.

Table 3.2
The characteristics of the panel members of the focus group meeting

Expert Code	Gender	Ph.D.	Profession	Area of the Study	Years of Experience
KSEE1	Female	Ph.D. in Science Education	Professor of Practice in Education and Engineering	Engineering and Science Education	15+
KSEE2	Female	Ph.D. in Science Education	Professor of Science Education	Science and STEM Education	15+
KSEE3	Female	Ph.D. in Engineering Education	Assistant Professor of STEM Education	STEM Education	5+
KSEE4	Female	Ph.D. in Science Education	Associate Professor in Teaching and Learning	Science and Engineering Education	10+
KSEE5	Male	Ph.D. in Science Education	Professor of Science Education	Science and STEM Education	15+
KSEE6	Male	Ph.D. in Science Education	Associate Professor in the Department of Education	Science and STEM Education	15+

Note: KSEE: K-12 Science and Engineering Education

The focus group meeting lasted approximately one hour. During the meeting, the panel members were presented a list of epistemic aspects of engineering drawn from the Delphi study and then, asked to which epistemic aspects of engineering knowledge, engineering design process, engineering design and values, norms and rules of the engineering community should be an integral part of K-12 education. The themes excluded from the list at the end of Round 2 were also discussed during the focus group meeting. At the beginning of the meeting, the researcher made a presentation to briefly explain the purpose, methodology, and findings of the study. Next, the group members were provided time to reflect on their opinions about each aspect. After that, the researcher asked the panel members of the focus group to share their ideas with regard to each question. At this stage, there were group discussions and the ideas of each panel member were recorded verbatim. All ideas then were summarized to ensure a common understanding. At the last stage, group members were invited to rate the importance of each theme to the K-12 science and engineering education on a 5-point Likert scale, with 1 indicating the lowest degree of importance and 5 the highest degree of importance. The scale included the final list of epistemic aspects of engineering obtained from the Delphi study. Additionally, four epistemic aspects of engineering, excluded from the list as their ratings did not meet the consensus criteria, were also included in the scale. Those four epistemic aspects including the themes of *Being Methodical*, *Uncertainty*, *Sustainability,* and *Desire to Serve Humanity*.

All videotaped interviews were transcribed verbatim and the explanations of group members were analyzed. After the analyses of the findings of the Delphi study and the focus group meeting were completed, theoretical coding was performed to specify the relationships between codes, which helped the researcher “move the analytical story in a theoretical direction” (Charmaz, 2006, p. 63). Throughout the data collection and analysis procedures, I also engaged in memo-writing to keep track of the thoughts, early interpretations of, and connections between codes which helped the researcher find the directions to follow. Summary of the data collection and analysis procedures were shown in Figure 3.3.

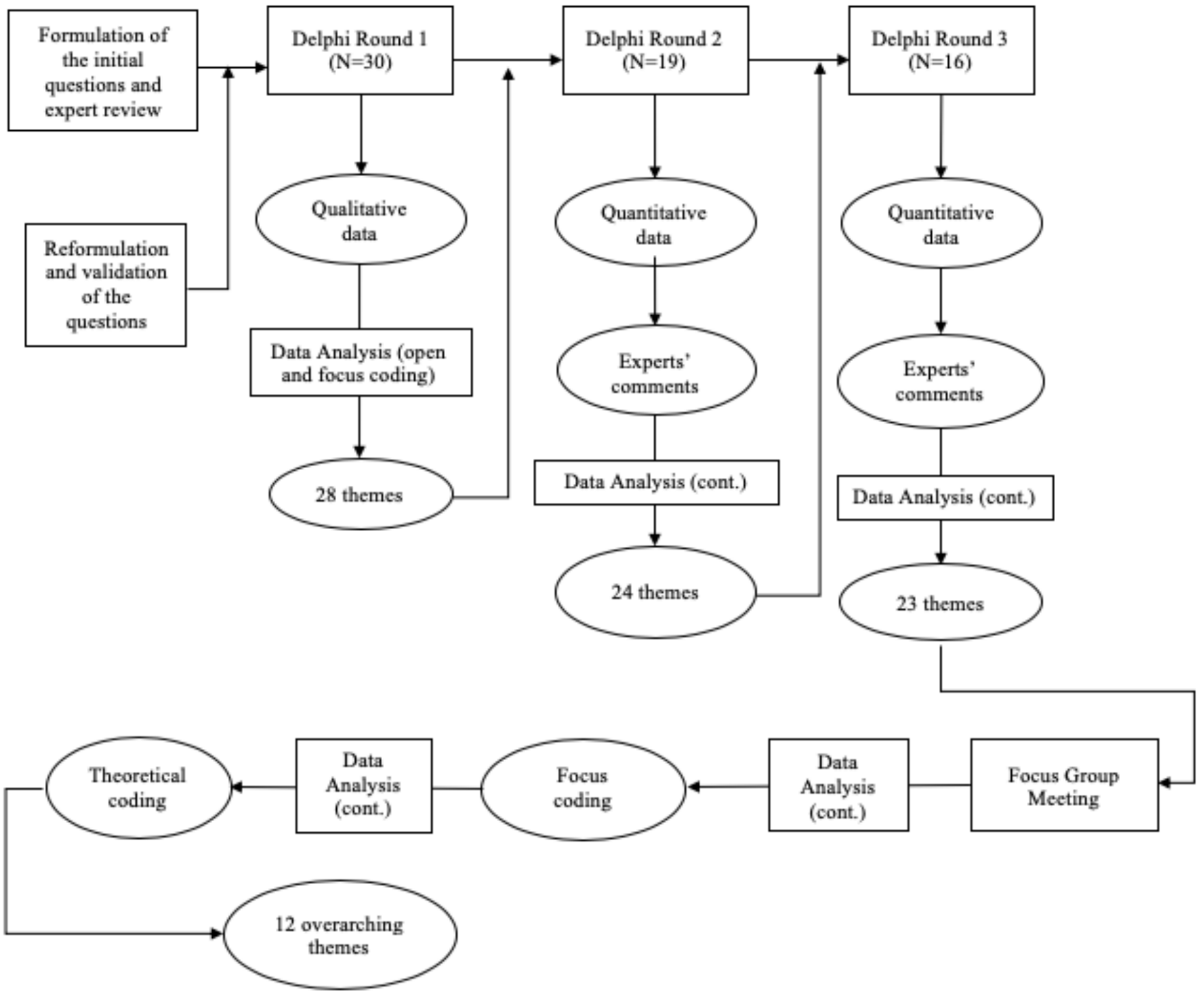

Figure 3.3 The design of the study

Trustworthiness

In this study, three major criteria were taken into consideration to ensure validity including reflexivity, member-checking, and peer debriefing (Schwartz-Shea & Yanow, 2013).

Reflexivity (Critical Subjectivity)

Reflexivity corresponds to the researchers' self-reflection on their presuppositions and biases. In interpretive research, instead of trying to omit the influence of the researcher's presence, the interpretive researcher should acknowledge that through reflexivity (Schwartz-Shea & Yanow, 2013). Therefore, it is important to make their contribution explicit throughout the research by providing information about the researcher's characteristics, background, and role in the study. In this way, reflexivity helps researchers to make their overall contribution to the research transparent for readers, which in turn improves the trust in their knowledge claims and analyses. In the following paragraphs, the researcher's background and role in the study were discussed.

I identify myself as both researcher and educator, having research experience in K-12 and science and engineering education and teacher education, together with having teaching experience in elementary schools and higher education. I am particularly interested in elementary and pre-college engineering education. Although the courses that I have taught in higher education have primarily been science teaching methods courses, I have integrated engineering units in the courses to help pre-service elementary teachers integrate engineering into their future science classrooms. Also, as a part of a grant project funded by the National Science Foundation (NSF), I have iteratively and collaboratively co-developed curricula integrating engineering, science, math, and language arts. Furthermore, I collaborated to provide professional development workshops to elementary teachers and students around these integrated curricula. My work on this project has led to conference presentations and several publications.

My teaching and research experiences led me to form my beliefs with respect to engineering education. I believe that even though K-12 engineering education is still an emerging research area, it has the potential to improve students' understandings of various topics. Therefore, it is of my belief that the epistemology of engineering could contribute to K-12 science and engineering education and curriculum developments.

Even though the constructivist grounded theorist acknowledges the role of subjectivity in data analysis, this does not imply that the researcher is allowed to purposefully force the data to fit the researcher's predispositions. On the other hand, the aim of the constructivist grounded theory method is to provide reflexivity in order to maintain consciousness of their preconceptions and subjectivities. Thus, the researcher aimed to give priority to what the data indicate rather than relying on her predispositions. Still, the aspects formulated during the data analysis procedure were co-constructed by the participants and the researcher, thereby inevitably reflecting my interpretations (Charmaz, 2006).

Member-checking

Interpretative researchers are aware that the knowledge claims are constructed by the interaction between the researcher and the participant. From this perspective, the participants' perspectives could be interpreted in diverse ways. Therefore, member-checking is considered to be an important component of interpretative research. In this study, member-checking interview sessions were conducted to obtain each participants' reflections on the conclusion derived from earlier in Round 1 at the beginning of Round 2 and Round 3. Additionally, the researcher conducted formal and informal interviews to ask the participants to elaborate on their statements.

Peer debriefing

After the analysis of the Delphi study with the expert panel was finalized, the findings were reviewed and discussed by the panel members of the focus group including only K-12 science and engineering educators who were familiar with engineering education to tailor the findings to the K-12 education, which in turn, improved the conceptual framework for epistemic aspects of engineering.

Chapter 4

Findings

The purpose of this study was to ascertain the epistemic aspects of engineering through the Delphi study. The Delphi study expert panel comprised experts doing research on the philosophy of engineering and technology, practicing engineers and science/engineering educators/researchers. The Delphi study findings were presented to K-12 science and engineering educators in a focus group meeting to determine the most relevant epistemological aspects of engineering for K-12 science and engineering education. After the themes were ascertained, theoretical coding was employed in order to identify the overarching themes that highlighted the epistemic aspects of the engineering discipline. The findings of the current study were presented in the three sections. The first section presents the themes derived from the Delphi study in the four distinct subsections: (a) the knowledge base for engineering, (b) the stages of the engineering design process, (c) the key aspects of the engineering design; and (d) the values, norms, and rules of the engineering design community. The second section presents the findings gathered from the focus group meeting. The suggestions concerning the overall findings and the relevancy of epistemological aspects of engineering for K-12 science and engineering education were included in this section. The last section presents the overarching, abstract themes derived from both the findings of the Delphi study and focus group meeting. The following subsections of this chapter used the expert panel members' accounts to explore deeper into each epistemic aspect.

The Findings of the Delphi Study

This section portrays a narrative to highlight how the process of the Delphi study proceeds, starting from Round 1 to Round 3. To be more specific, this section illustrates the iterative process of the Delphi study in which the following themes were continuously constructed and reconstructed throughout the Delphi study. The first round produced twenty-eight epistemic aspects, some of which were revised, modified, or excluded from the list of the epistemic aspects of engineering in the subsequent round. See Appendix A for the final version of titles and descriptions of epistemic aspects of the knowledge base for engineering which reflect the essence of the panel members' ideas.

Knowledge Base for Engineering

In the first round, six forms of knowledge for the engineering discipline were identified, including scientific knowledge, mathematical knowledge, technological knowledge, engineering knowledge, social knowledge, and experiential knowledge. However, social and experiential knowledge categories were subsumed under the category of engineering knowledge in light of both quantitative and qualitative results. Table 4.1 indicates the mean and modal ratings as well as standard deviations for each theme obtained from Rounds 2 and 3.

Scientific Knowledge. The theme of scientific knowledge as a dimension of the knowledge base of engineering was suggested by twenty-three panel members who are researchers in the fields of philosophy of engineering, science/engineering educators, and practicing engineers. It seems that there was an overall consensus on scientific knowledge constituting one of the basic forms of knowledge that engineers should have across Rounds 2 and 3 (Round 2: M= 4.63; SD= .6; Round 3: M= 4.56; SD= .63). One panel member, for instance, stated:

> When designing engineering solutions, engineers use knowledge of fundamental sciences such as physics, chemistry, and biology. Depending on the type of project/solution sought

> one of these sciences would become more important than another. But in all cases, the science fundamentals are essential. (EEPE7)

Scientific knowledge is essential to understand how technologies function as "modern technologies that engineers work on frequently operating on the bases of physical laws and properties of matter that require a relatively sophisticated level of scientific understanding to exploit" (EEP1). Being able to create innovative design ideas does not only require creative skills but also a strong understanding of underlying scientific principles: "Engineers use fundamentals of science and physics to understand how and why things function the way that they do. This understanding leads them to be inventive and innovative" (PE2).

It is the scientific knowledge that is underlying designs and "that separate engineering designs from just a matter of artistic designs" (EE4). Some of the panel members cautioned against the use of scientific knowledge in the design process does not mean engineering being about the mere application of science:

> I think it is not just math or science, but it is the math or science as applied within engineering, so I think that physics is a fundamental concept, but I see it in an engineering context that it is not enough that they have the fundamentals. They may know how to do work energy in physics or how to differentiate from calculus, but they need to know how to look at that through an engineering lens and so, they are differentiating or integrating it and see it from an engineering standpoint. (EE11)

Mathematical Knowledge. As in scientific knowledge, there was a high consensus on the theme of math knowledge across all rounds (Round 2: *M*= 4.53; *SD*= .61; Round 3: *M*= 4.5; *SD*= .63). Fourteen panel members suggested the inclusion of math knowledge as a form of knowledge that is required for engineering work in the first round. One panel member, for example, asserted: "Given the quantitative nature of engineering design work, engineers need extensive knowledge of applied mathematics" (EEP6). Mathematical knowledge and tools are embedded into many aspects of engineering activities: "Math is usually necessary for the proper application of underlying scientific principles, and for understanding the performance, safety, etc. of the engineering solution" (PE1). Also, especially for complicated solutions, "the mathematical analysis to predict and model, and optimize a solution is uniquely characteristic of the engineer. This knowledge is important because it enables the engineer to optimize and not compromise the safety and effectiveness of a solution" (EE9).

Further, one of the panel members mentioned the necessity of quantitative analyses for precision: "the reason why engineers are generally needed to do the jobs for which they are hired is that precision is required. That precision requires quantitative work, which in turn demands certain types of quantitative analyses" (EEP6).

Technological knowledge. Several panel members indicated the knowledge of tools, materials, parts and technologies, and technological systems that engineers need to master. This type of knowledge, labeled as technological knowledge, suggested by ten panel members was coupled with a high degree of consensus across Rounds 2 and 3 (Round 2: *M*= 4.47; *SD*= .7; Round 3: *M*= 4.56; *SD*= .63). This aspect covers the knowledge of existing technologies and how they work. The participants, for instance, pointed out the importance of the knowledge about technologies in the design process. Consider the following statements:

> Engineers will need to have a good understanding of how most technologies work, from large equipment to 3D printers and lasers. With a good understanding of the technologies, we can use for completing a solution, engineers are able to choose the appropriate path in which to solve the problem. (EEP8)

> Engineers must have a knowledge of (some) tools and how they can be used. This seems simple, but many who start out in engineering programs have very little knowledge of tools--from band saws and drill presses to 3d-printing and basic circuitry. You can only design an effective product if you know what is possible and this requires some level of understanding of what can happen in a machine shop or a simulation suite. While it is impossible to know what all tools everywhere are capable of, having knowledge of what a wide range of tools is capable of will be a huge advantage in the design process. (EEP5)

Another participant mentioned merely having a good understanding of science and math is not sufficient for design work in engineering discipline:

> The whole reason engineers have specializations is because they need to understand certain technological systems in order to engage in meaningful design. Modern technologies are extremely complex. Even someone with extensive mathematical and scientific knowledge would be utterly bewildered by most of the technological systems in the modern world. The only way that they can be developed is if people with specialized knowledge of the systems themselves are doing that work. (EEP6)

One of the panel members highlighted the necessity of having an understanding of why tools and technologies work the way they do for approaching a design work in a different manner as follows:

> It is difficult to even figure out what needs an engineering solution if you do not ask, "why is this the way it is?" or "why is this done the way it is done?" Engineers must be able to break through the abstraction of humans from current technology to understand why things are actually done the way they are. So in other words,....they do not just use a tool as a tool--they seek to understand why a tool works the way it does. Because it is

> only once you get to this level of understanding that you can figure out how you might do it differently. (EEP5)

Another panel member made a distinction between “normal” and radical design, and the necessity of the knowledge of technologies, regardless of the type of designs:

> They (engineers) generally are not creating a new production process from scratch; rather, they are modifying an existing process to meet a specific situation. If the design engineers did not have intimate knowledge of what goes on within the technological systems at the facility, their designs would be useless….this is the typical case for engineering design, and some scholars call this "normal" engineering design. More "radical" design would occur when the designers are not simply modifying existing processes but creating something more novel (though nothing is completely novel). Even in that case, though, the most important knowledge base is technological. (EEP6)

Experiential Knowledge. In the first round, the knowledge about existing technological solutions to similar problems, failures, and the techniques used to produce technologies as well as knowledge based on experience and rules of thumbs was labeled as *Experiential Knowledge*. For instance, one of the participants stated:

> The knowledge of how similar (if unrelated) designs have worked in the past. Lack of understanding of how similar designs have worked leads to "spinning our wheels" rediscovering and solving problems that have already been solved. Products/solutions designed without this knowledge may work but are lackluster when compared to competitors. (EEPE1)

Another participant emphasized the advantages of knowing existing solutions as “existing tools and solutions are useful because relying on them saves time, avoids redundancy, leverages time-tested ideas, and helps create solutions that are compatible with existing systems" (PE1). This form of knowledge proposed by twelve panel members was associated with a low consensus level (Round 2: *M*=3.89; *SD*=.81), as compared to most aspects that were rated as fairly or very important. Since the ratings of the theme did not meet the consensus criterion, the aspect was excluded from the list of epistemic aspects of engineering.

However, two of the panel members, in Round 2, commented some of the elements of this theme are overlapping with the theme of technological knowledge and engineering knowledge which includes knowledge about existing technological solutions, and techniques used previously: "Number 6 (experiential knowledge) could be subsumed under either technological knowledge or engineering knowledge" (EE7); "I am not certain that technological knowledge and experiential knowledge are all that different. If you have some knowledge of how the technologies have evolved over time, then you have experiential knowledge" (EEPE5). Hence, the decision was to integrate these elements into the *Technological Knowledge* theme for Round 3.

On the other hand, the experiential knowledge, as several panel members indicated, is not only about an understanding of existing technological solutions but engineers' own design experiences, past design failures and rules of thumbs which is hard to articulate but derived from the design experiences also count as experiential knowledge. A panel member, for example, contended: "When designing solutions, I believe a large degree of experience is needed" (EEP3). In the same vein, another panel member drew a distinction between design approaches that novice and experienced engineers use in the following observation:

> For many engineers, the design process has become their inherent way of thinking and a natural approach for problem-solving… there is a difference between a novice engineer

> problem solver versus a very veteran engineer problem solver…For engineers early in their training and careers, the process steps are usually very sequential and relatively easy to identify. As engineers become more experienced problem solvers, there is more of a flow between the steps. (EEPE2)

In that regard, one panel member expressed his concern in Round 3 that experiential knowledge is not about knowing previous technological systems but related to the “knowledge about when and how one should apply technical knowledge which is very different from technological knowledge” (EEP4). Besides, another panel member (EEPE4) recommended merging the several elements of the experiential knowledge encompassing the knowledge derived from engineers’ experiences about the design approaches, the design process, design failures, etc. with the engineering knowledge since this type of knowledge typically pertain to the engineering knowledge and it could inform and facilitate engineers’ judgments and decisions about when and how to perform engineering tasks.

Engineering Knowledge. The panel members considered this form of knowledge very important across the last two rounds with means above 4.50 (Round 2: *M*=4.63; *SD*=.5; Round 3: *M*= 4.69; *SD*= .6). In Round 1, several panel members pointed out a different body of knowledge encompassing the knowledge of engineering design methodologies, the use of science and math knowledge for engineering designs and theoretical knowledge unique to the discipline of engineering: “In my opinion, the core of engineering knowledge is the ability to apply a scientific understanding of the world (physics, chemistry, biology, psychology) to create a product, system, or process that will behave in the desired way (design)” (EE4). However, the point made here was not the use of pure scientific knowledge as it was emphasized that engineers need to transform and reconstruct the knowledge from natural sciences to generate design ideas.

Consider the following statements from the panel members who previously worked on the area of philosophy of engineering and in the industry: “Engineers must have expertise in science and math. This seems obvious, but a command of science and math and other technical knowledge is what makes an engineer special and able to do things that non-engineers are unable to do” (EEP5). Also, another participant endorsed this view by stating that:

> Engineering is more than science, is not the same level as the purely scientific level. Engineers do science but engineering is a field in my belief is aim at working towards making a practical item, scientists understand why things work the way they do, engineering applies the fundamental science engineering applies into something more practical. Engineering is more than just an applied science. (EEPE7)

In order to explicitly articulate this point, two of the panel members referred to the knowledge specific to engineering as engineering science knowledge as follows:

> Some of that knowledge because it requires strong scientific basis, I mean you have physics, you have chemistry so certainly they use that but they also use essentially now what we refer to is engineering science knowledge which is somewhat different than physical science and natural science knowledge because it was developed primarily for use by engineers, primarily for use to design artifacts. I do not know whether you call that scientific knowledge or not, but the typical person does not make that distinction, they do not distinguish between scientific knowledge and engineering science knowledge. (EEP4)
>
> For instance, thermodynamics is taught differently to engineers than it is taught to physicists, it is the same basic idea but the goal of it is different. That means engineers use both, any scientific knowledge that works for them, any engineering science knowledge works for them, any empirical knowledge works for them. There are lots of

> things we design, we use test results and they do not have a strong scientific knowledge, maybe not even engineering scientific background and we use test results, other heuristics, other rules of thumbs that allow them to make decisions when they do not have that all the information, whatever all the information would be, they never have all the information. Not never when designing something so simple but I am thinking about designing something new. (EEP4).

The knowledge of the engineering methods and technical knowledge that is needed to perform the design activities were also indicated as a dimension of the engineering knowledge. Consider the following observations:

> Fundamental understanding of the technical principles that will govern and constrain the design. Lack of knowledge of engineering fundamentals will prevent a great idea from becoming a reality. We see this when children try to build things but do not have the knowledge to make them work. Disappointment ensues. (EEPE1)
>
> Engineers need to have scientific (e.g., physics, forces) and engineering (e.g., how to test a solution) knowledge. (EE8)

To illustrate the importance of this knowledge in engineering design which could vary depending on specific engineering fields, one of the panel members who is an engineering educator provided an example related to her field, chemical engineering as follows:

> There is a basis of technical knowledge that is necessary and engineering specifically I am a chemical engineer which means that in theory, I should be able to design engineering equipment related to chemical processes and within that realm, there is a degree of technical knowledge I need to know and that can vary from specialty to

> specialty but for example, if I work in fluid systems and piping I need to know specifics about flow through pipe how to pipe diameter affects it. (EE5).

One panel member argued that engineering was more about practical knowledge, or in other words, how to approach to solve a problem than how to apply knowledge to design problems as indicated in the following statement:

> In my opinion, the nature of the knowledge that engineers use when designing engineering solutions is the knowledge of the process itself. Being an engineer and designing engineering solutions is not about what engineers know. It is all about how engineers think. Many engineers share a similar knowledge base and yet are able to develop unique engineered solutions based on how that similar knowledge bases are applied. For many engineers, the design process has become an inherent way of thinking and a natural approach for problem-solving. In this regard, the development of an effective engineering solution is less about the engineering knowledge applied and more about how that knowledge is applied. (EEPE2)

Additionally, as mentioned above several elements of experiential knowledge that was given a separate category in Round 2, was combined with the engineering knowledge in light of the panel members' comments.

Social Knowledge. In the first round, eleven panel members proposed the inclusion of social knowledge as an important body of knowledge for the engineering discipline. The panel members underlined the importance of understanding social needs, human behaviors, and implications of designs on society and environment in design solutions as the following observation indicates: "Engineering solutions are solutions to social needs. For an engineering solution to be appropriate, the social need must be well understood, which includes understanding something about the social benefits, the social costs, the ethical implications, the environmental ramifications" (EEP1).

In order to emphasize its significance for engineering discipline, one of the panel members provided an example related to the use of social understanding in engineering design as follows: "Engineers need to understand…relevant social aspects. A traffic problem would need a solution that incorporates the understanding of drivers' behavior. An improved home oven would need an understanding of the cook's preferences" (EEPE7). By the same token, in some engineering fields, it is difficult to determine technical requirements because it depends on how the product will be used as one panel member indicated in the following statement: "In some fields especially in the electronics industry, we do not know what the requirement is because we do not know exactly how somebody is going to use the product, like think about a cell" (EEPE1). In that case, engineers need to take possible end-user interactions with the design into consideration in the design process: "But we still go into the process saying people may want to be able to do this particular thing they may want the phone to have GPS and that type of requirement and data" (EEPE1).

Several panel members underlined the necessity of understanding target users' characteristics and behaviors as well as their needs and want as follows:

> Good designers understand human behavior and design products for their end-users. They care about the consequences that their products may have (i.e. safety, sustainability, etc.). Additionally, designers seek out what a customer really wants, and they use the resources they have at their disposal (i.e. locally sourced). (EEPE8)

As an engineering educator, she also noted the implications of this knowledge for education: “I want my students or even a designer to understand who's going to be using it at the end because you need to know where you are going at the end before you even get started”.

Another participant highlighted the necessity of design criteria for addressing end users’ needs and wants in the following statement: “It is important for engineers to understand the needs of the end-users and have consultations with them. Identifying the criteria that are important to help on the final decision of this design and the different weighting of the criteria” (EE6).

One panel member addressed that engineering, contrary to the common assumption, is not just about application science and mathematics but also about creating societal change:

> It is not just science and math. I think it is more about trying to create societal change in societal improvement through technology. It is so much more than science and math and it is going to continue to be so much more as our challenges get more and more complex and require more and more unique perspectives just having a mathematical understanding it is going to be insufficient and so it is a science and math are very important but there is much more to engineering. (EE5)

Similarly, several examples were also provided to illustrate the necessity of the understanding of the needs of society and the impacts of the design of interest. Consider the following example from the panel member who had experience in the industry:

> If you are going to have an automatic car you need to know whether society wants that. Also, if you are going to have a marketable solution then you have to consider the impact on society whether the society would want that kind of product. For example, we are improving cars you are placing more cameras in them, so it has to do with the fact that

> we want the driver to have the greater capability without the cameras and you have something to going to be marketable then you need to consider societal impact; what is society will be interested in that kind of a product, trying to understand the market and society better in terms of what they would need. (EEPE7).

Also, she added that engineering design is not always about satisfying the current needs of the society but also, engineering design could create a new need but even, in this case, engineers need to consider whether society would need or use the product:

> The first iPhone I do not know about anybody's needs was that. It created the needs; sometimes work like that as well but either case you have to understand in terms of who is going to use the product and how they use the product, so they need to incorporate that [understanding] to designs. (EEPE7)

This theme was considered less important to the engineering discipline as compared to the other themes. In Round 2, even though the theme was scored more than the mean cut-off point (*M*= 4.15), the standard deviation of the theme was found to be more than 1 (*SD*= 1.01), indicating relatively low consensus among the panel members. On the other hand, comments revealed that several panel members considered this theme as a part of the engineering knowledge. On the other hand, one of the panel members in Round 3 challenged with this revision:

> The summary states that engineers need an understanding of a rather broad set of "social aspects of engineering" but this reads more like a list of ideas related to how technology intersects with society. As much as I would like engineers to be knowledgeable about those things, most engineering is not actually done with very much attention to it.

> Engineers certainly need knowledge of relevant regulations and standards of practice. (EEP6)

In light of this comment, the revision was made to the summary statement to eliminate the broader knowledge of the social aspects of engineering. As the panel member suggested, having a broader knowledge about the social implications of engineering may not be relevant to all engineering subfields and engineers may not need to develop such a broader understanding.

Table 4.1

Engineering knowledge base and descriptive statistics in Round 2 and Round 3

Epistemic Aspect Title	Round 2			Round 3			Stability (%)
	Mean	Mode	*SD*	Mean	Mode	*SD*	
Scientific Knowledge	4.63	5	.6	4.56	5	.63	100
Mathematical Knowledge	4.53	5	.61	4.5	5	.63	100
Technological Knowledge	4.47	5	.7	4.56	5	.63	100
Engineering Knowledge	4.63	5	.5	4.69	5	.6	75
Experiential Knowledge	3.89	4	.81	N/R[a]	5	N/R[a]	-
Social Knowledge	4.16	5	1.01	N/R[a]	5	N/R[a]	-

Note: Consensus criteria: Mean > 4; Standards Deviation <1

Stability criterion: a change of one-third or less in the ratings (or >66.67)

[a] The themes of *Social Knowledge* and *Experiential Knowledge* were subsumed under the themes of *Technology Knowledge* and *Engineering Knowledge* in Round 3

The Stages of the Engineering Design Process

Several participants justified that the models of the design process which involves distinct stages do not represent the true nature of the engineering design process. The following comment provided by one panel member, for example, indicates:

> I am not a huge fan of the word stages here, because the word wrongly implied that what transpires during design occurs at discrete times in a certain order. While certain

> activities do tend to precede others, the major tasks that occur during design happen essentially on an ad hoc basis and tasks can occur more or less simultaneously. (EEP6)

Similarly, another panel member posited that "effective performance of the design process requires that these steps be considered and performed simultaneously within the larger stages" (EEPE2). On the other hand, as several participants voiced, it is important to identify the stages that engineers engage in for novices. Therefore, descriptions of the panel members regarding the stages of the design process were collated and based on the overlapping ideas, the following five stages were identified. Table 4.2 illustrated the mean and mode ratings and standard deviations for each theme.

Problem Definition. This theme suggested by twenty-nine participants was considered as "extremely important" (EEPE8) because if engineers do not have an understanding of engineering problems and a plan for how to produce design, designs will not be as engineers intend to be. Another participant also designated this stage as the most: "critical" stage in the engineering design process since "this stage occurs early in the overall process and in many ways determines the direction of subsequent activities" (EEPE2). *Problem Definition* stage encompasses the practice of "developing a thorough understanding of the problem to be solved" (EE4) which requires consideration of "what created the need for the design" (EE11).

In order to build a solid definition for engineering problems, engineers need to consider various aspects of an engineering problem. One participant specified those as scientific aspects, and social aspects specific to an engineering problem at hand as follows: "An understanding of the end-users as well as an understanding of the science of the physical system" (EE4). Several other participants added economic, environmental, and ethical aspects of engineering problems to this list as the following statement illustrates: "Problem definition-ideally a holistic (considering social, environmental, political, etc., factors as well as technical) and stakeholder analysis. This is important because otherwise you might be wasting time and resources and designing something that is not what is needed" (EE5).

In Rounds 2 and 3, the highest priority was given to this theme among the stages of the engineering design process (Round 2: *M*= 4.74; *SD*= .56; Round 3: *M*= 4.69; *SD*= .6). For instance, one of the panel members pointed out the importance of constructing well-defined problem statements in design processes as follows: "I have long felt that many engineering design failures can be traced back to poorly or inappropriately defined problem statements" (EEP4).

Besides, several participants noted that an engineering problem definition may not remain the same while engineers continue working: "The boundaries of the design problem often take shape as engineers work on the task, and specifications/criteria are often re-negotiated between the stakeholders at multiple points in time" (EEP6); "Defining the "problem"-truly understanding what issue is it hand and remaining open to altering and/or adding to the established problem over time" (EEPE6).

Identification of Design Requirements and Specifications. In Round 1, there was a variance in assigning the identification of design specifications and requirements to the problem definition phase. Several panel members mentioned the practice of determining design requirements and constraints in conjunction with the problem definition phase. The decision in the first round was to integrate these engineering practices under the *Problem Definition* theme because of the relevant elements. However, one of the panel members suggested in Round 2 keeping understanding the problem and design requirements separate as "understanding or confronting the problem is about the need while requirements constrain the solution" (EEPE4).

This indicates that the practices performed in these two phases may be qualitatively different. In the problem definition phase, engineers do research to identify an engineering problem or a need while in the identification of requirements and specifications, engineers search and determine what acceptable solutions could be in the light of design criteria and constraints. For this reason, in order to minimize the overlap of the ideas between these two aspects, the identification of design requirements and specifications was regarded as a distinct engineering design stage in Round 3.

This theme includes the practices of “determin[ing] the main function of the product, as well as any objectives for the design and constraints that bound the problem” (EE4). Within this phase, engineers “need to know what parameters he/she will be working under - what materials? size? speed? end-use?” (EEP7) as well as “what are the requirements? what are the restrictions? and what resources are available or missing?” (PE1). Engineers, in this phase, are “outlining desired outcomes and assessment – it is important to know what success means for the design to know what you have achieved” (EE5). One panel member provided an example which indicates how technical design requirements for the design are established as follows:

> If you are designing a new airplane, you want to know how many passengers they can carry and how far it can fly and how much it is allowed to weigh and things like that those are concrete requirements that we really need to [determine]. If the design cannot do those things it is not a viable design. (EEPE1)

One of the participants stressed the inclusion of the consideration of “the consequences that their products may have (i.e. safety, sustainability, etc.)” into this phase (EEPE8). In order to provide a context for the concept, one participant provided an example as follows:

> One needs to understand what would be considered an acceptable solution (or within a range of acceptable solutions). There are scientific and social aspects of what is an acceptable solution. For example, a product may need to meet some technical and/or legal requirements (e.g., be able to withstand at least a certain amount of pressure or work at a certain, built to local code). Social components of what would be considered an acceptable solution might include economic and ethical considerations (e.g., stay within the budget set by local government while minimizing the effects of a design on the environment). (EE8)

One participant emphasized how technical, mathematical, and scientific knowledge are integrated into this phase as follows: “The technical has to do with developing specifications, the mathematical has to do with being able to quantify, and the scientific is to be able to understand the natural expectations of the problem and the solution's elements” (EE9).

In Round 3, the last round, this theme was regarded as important or very important to the engineering discipline as the mean ratings indicate (Round 3: *M*= 4.56; *SD*= .63).

Idea Generation. This theme, initially suggested by twenty-seven panel members, considered as an important or very important epistemic aspect (Round 2: *M*= 4.32; *SD*= .95; Round 3: *M*= 4.38; *SD*= .62). While several labeled this phase as idea generation or conceptual design, few referred to “generating multiple solutions” (EE4), “preliminary layout” (EE1), or “conceptual design” (EEP1). The question that engineers explore within this phase is to “what are the possible ways to solve the problem within the existing constraints?” (EEP1). During this phase, engineers brainstorm various potential design ideas that could be used to solve the identified design problem.

In this phase, it is important for engineers to “ideally get multiple perspectives” (EE5) “because it may turn out that one is better than another for various reasons” (EE9). Therefore, “engineers need to be open-minded while being realistic about possible solutions to the problem” (EEP8). This phase also involves the practices of drawing/ sketching prototypes (conceptual design-technical drawings), if necessary, which helps the construction of prototypes. However, it is worthy of note that one panel member (EEPE4) suggested considering the idea generation phase as an idea expansion process and conceptual design as an idea contraction process in which solution ideas are refined.

Several panel members also stressed that idea generation phase could be revisited during design processes as follows: “At any point in the process, engineers may need to go back to the drawing board and start back at this stage” (EEPE8); “Designers will often do quite a bit of this early on, but idea generation tends also to continue throughout the process as needed” (EEP6).

In Round 2, two of the panel members recommended the inclusion of the practice of searching for existing materials, approaches, and solutions in the theme. Consider the following statements: “It is often more feasible to use materials and approaches from "off of the shelf" if they already exist” (EE9); “The Stages of Engineering Design Process appears to focus on a prototype design. Many engineers choose products out of a book that meets the design parameters” (EEPE3). However, one of the panel members challenged this view as follows: “I am not sure about searching for existing solutions. Presumably, the solution does not already exist, which is why we are doing the process. It seems like it should just be “searching for solutions” (EEP1). Therefore, the further revision to the summary statement was made such that searching for existing materials and approaches and sometimes existing solutions in order to build on existing designs (improvement/updating) or in order not to replicate someone else's design.

Idea Evaluation. This theme, suggested by twenty-five panel members, ascribed high importance (Round 2: *M*= 4.42, *SD*= .69; Round 3: *M*=4.44, *SD*= .73). Within this phase, engineers assess initial idea solutions to eliminate the ones that do not seem feasible or practical. Assessments are performed with the following questions in mind: "How do they address the problem, what aspects do they not address in the problem, what are the benefits and limitations of each idea, can ideas be combined/separated/adjusted" (EE11). In other words, engineers compare the pros and cons of possible solution ideas based on identified criteria and constrained.

In Round 3, one of the panel members suggested the inclusion of qualitative analysis to assess possible solution ideas before prototyping as modeling or prototypical all possible design ideas may not be feasible. The panel member expressed that:

> If the concept generation phase produces many ideas, it will be a difficulty and not possible to prototype them all or model them all, in order to narrow them down. Most concepts are weeded out through a much more qualitative process -- creating decision matrices, for example, with ratings and rankings based on perceived qualities and drawbacks of various concepts. I think for many, if not most, designs, the only prototyping done is for the selected concept and subsequent possible revisions of it. (EEP1)

As the panel member suggested, a qualitative analysis which typically includes decision making matrices with ratings and rankings based on established design specifications including design criteria and constraints were integrated into this theme. Another panel member suggested the evaluation of potential idea solutions "evaluated from physical, safety, economic, and user perspectives until only a few solutions remain" (EEPE7).

In a similar vein, one participant stated engineers "use a process to choose the best solution: this might be a weighted mathematical calculation, based on requirements such as cost, safety, availability of existing materials and expertise" (EE9). Another participant mentioned a formal evaluation as: "Set up a formal evaluation with the final prototypes. The evaluation should link back to the original functions, objectives, and constraints, while also allowing for the identification of unforeseen problems as well" (EE4).

After the evaluation, initial idea solutions are narrowed down to a few or one possible design idea as several of the panel members suggested. For instance, one of the participants viewed that in most cases, one solution idea is selected for the prototype-testing phase: "I think for many, if not most, designs, the only prototyping done is for the selected concept and subsequent possible revisions of it" (EEP1). This solution should be "the idea that best fits the situation [engineers] are in and the constraints that are on the team" (EEP8).

After the selection of the best idea solution(s), engineers may need to create models in order to test, evaluate, and determine whether a particular design idea(s) meets identified specifications. Engineers "create a prototype (or preferably prototypes)…to test the feasibility of designs" (EE4). In order to do so, detailed design in the form of a functional prototype or a model is created. One of the panel members labeled this phase as an embodiment design phase where engineers determine "what the details are needed (parts/materials/etc.) to realize the concept in the form of a working prototype" (EEP1).

Within this phase, it is important to consider "how feasible each of the solutions is, to what level they address the problem, whether they create additional problems when implemented, what the economic, societal, environmental costs of the solution are" through "modeling and predictive analyses" (EE11).

Several panel members mentioned that in addition to feedback obtained through testing, engineers also seek input from stakeholders, ultimate end-users, experts, and the community during the evaluation process: "Idea evaluation should include feedback from others (e.g., clients, experts, community impacted) that also inform the redesign. This form of feedback, in addition to testing, allows engineers to know if the idea is on track to solving the problem" (EE8).

One of the panel members noted that the process of design idea evaluation is not a linear process: "It is also important to note that the process is not always so neatly linear. Sometimes it is best to move back based on difficulty in prototyping, or unacceptable results in the evaluation" (EE4).

On the other hand, engineering design processes do not always involve creating physical prototypes to evaluate design ideas. Five of the panel members highlighted the important distinction between prototypical and non-prototypical engineering designs including structures like bridges, buildings, etc. for which building physical prototypes is not possible. One of the panel members who were researchers in the area of philosophy of engineering and engineering education, for instance, expressed concerns over the summary statement at the end of Round 3: "Idea evaluation puts too much emphasis on prototyping and modeling, in my opinion. I agree with the suggested revision about feedback" (EEP1). Hence, the summary statement was revised in a way that gives more emphasis on the evaluation of design ideas for a non-prototypical engineering system. In that regard, one of the panel members specified the evaluation process as follows: "Non-prototypical systems require a more conservative approach to design. Quality assurance at all levels (Checking of designs, testing, and inspection and design during fabrication/construction.)" (EEP4).

The panel member added that engineers receive feedback from quality assurance as well as failures may provide feedback to designs after the construction. Hence, the final statement included the following ideas: instead of obtaining direct evidence from testing and evaluating physical prototypes, in a non-prototypical design, engineers employ quality control methods and peer reviews during the construction phase.

Design Refinement. Twenty-six panel members considered the idea refinement as an essential element of the engineering design process (Round 2: *M*= 4.58, *SD*= .77; Round 3: *M*=4.56, *SD*= .63). Within this phase, following evaluations of design ideas, solution ideas are either ruled out or gone through the refinement or redesigning process. Engineers redesign or modify solution ideas "when [they] run into failures through testing" (EEP8). Also, engineering design ideas are refined and optimized for economical production and use by customers/consumers (EEP1). During this process, engineers obtain feedback from stakeholders again. In other words, the refinement process "gets us [engineers] closer to what the end-user desires" (EEPE8).

One of the panel members further justified the importance of this theme in pre-college and college education in Round 2 and compared its real-life applications in industry and education: "Idea refinement is often an under-taught part of the design process. This is where a huge amount of time and effort is spent in the industry, but K-12 and college projects often cut this part of the process short" (EE4).

Several panel members underlined the need for iterations in the design process "until success criteria are met" (EE5). Iterations should be also made when new information is available: “The iterative process continues until a solution is identified that is considered sufficient. Depending on if new information is surfaced during the development, it may be necessary to revisit the problem definition and criteria and constraints” (EE8). Two of the panel members added that iteration process could begin earlier: “Engineers can begin the iterative process of solution conception in the idea generation process (which may include developing a prototype)” (EE8); “Idea refinement, in general, can begin essentially as soon as idea generation occurs” (EEP6).

When a sufficient design is created, “the final option will enter a "detailing" process in which the polished design will be produced” (EEP6). That is the phase where “the concept's details are filled in with actual parts, materials, sizes, etc. The detailed design process takes place near the end of the design process” (EEP1).

Three participants expressed the need for the inclusion of the value design in the engineering design process. One participant, for instance, explained that the value design could begin as early as at the beginning of the design process or in idea refinement phase as follows:

> Value analysis through which they [engineers] can improve the products, improve the features, and reduce cost. Engineers try to improve or optimize either a product, a piece of hardware or a procedure or system. It could even be a program; it can be done either before you decide to do something or if you have a product you wish to improve. (EE2)

Table 4.2

The stages of the engineering design and descriptive statistics in Round 2 and Round 3

Epistemic Aspect Title	Round 2			Round 3			Stability (%)
	Mean	Mode	*SD*	Mean	Mode	*SD*	
Problem Definition	4.74	5	.56	4.69	5	.6	87.5
Identification of Design Specifications and Requirements	N/R[a]	N/R[a]	N/R[a]	4.53	4	.64	-

Idea Generation	4.32	5	.95	4.56	5	.63	68.75
Idea Evaluation	4.42	5	.69	4.27	5	.8	87.5
Design Refinement	4.58	5	.77	4.56	5	.63	68.75

Note: Consensus criteria: Mean > 4; Standards Deviation <1

Stability criterion: a change of one-third or less in the ratings (or >66.67)

[a] The theme of Identification of Design Specifications and Requirements were given a separate category in Round

Key Aspects of Engineering Design

In the first round, twelve themes were identified for the key aspects of the engineering design. However, in the second round two themes did not meet the consensus criteria (Mean >4 and Standard Deviation <1), therefore not included in the third and last round. See Table 4.3 for the ratings across rounds.

Communication. This theme was suggested by almost all participants and thus, one of the highest-rated themes across the last two rounds (Round 2: M=4.84; SD=.37; Round 3: M= 4.63; SD= .5). One of the panel members even claimed that 70% of engineering work is communicating in teams and with stakeholders (EE5). Several panel members claimed that engineers have to communicate not only with other engineers in teams but also experts from multiple fields. Consider the following statement:

> Engineering projects often cut across not only multiple individuals, but multiple teams, multiple divisions of a company, or even multiple companies involving contractors, subcontractors, and vendors. Therefore communication, coordination, and logistics within and between organizations are often crucial to the success of engineering projects. (EEP1)

One of the panel members suggested that communication skills are necessary for the engineering discipline in order to articulate processes that they go through and the end-product that they create:

> Engineers have to have strong communication skills because if they have done a design or an analysis and they cannot communicate, or in other words, if you cannot convey what you did, how you did it and the importance of it only resides with you and you have not transferred the knowledge to someone else. (EEPE1)

Similarly, another participant underlined the crucial role of communication in justifying their engineering design ideas as well as understanding what end-users and society in general needs and wants or other words, understanding what they are designed for in the following statement:

> Engineers need to be able to listen and communicate effectively. Most people will point to communication skills as necessary for engineers because if they cannot explain and sell their idea, then it is not going to help anyone. However, this skill is also critical to designing inclusively. If engineers only designed for themselves, then they would only have to understand their own experiences and desires. However, engineers are tasked with developing for humanity. In this case, the only way to understand the experiences and desires of a person outside of your daily life is to listen and work hard to understand their situation. (EEP5)

Another participant highlighted the necessity of communication throughout engineering design processes: “The engineering must be able to communicate technically analysis, the solution, its requirements, and specifications, how it was optimized, and how it should be tested, implemented, and monitored” (EE9). In the second round, one of the panel members asked for the revision of the summary statement of the communication theme by adding the necessity of communicating engineering problems: “Engineers need to communicate the problem as well. The problem statement may change over time and they may get a clearer picture of what it is they are really trying to do with their design” (EE7). Hence, the summary statement was revised such that communication is essential for all phases of the engineering design process.

Two panel members classified the communication theme as a norm/value of the engineering community. Most of the panel members mention communication as an important aspect of the engineering design process or as an integral part of the design process (communicating problems and solutions), thereby including the theme as a key aspect of the design process in the list. On the other hand, the communication aspect was also regarded as a norm of the engineering community that reflects communication norms.

Collaboration. There was a particular emphasis on the importance of collaboration in the engineering activities in the first round and thus, it was rated as important or very important across Round 2 and Round 3 (Round 2: *M*=4.63; *SD*=.6; Round 3: *M*= 4.56; *SD*= .63). The importance of collaboration in the engineering discipline was stressed by twelve participants. In engineering, the concept of teamwork “includes collaborating well with others, seeking advice, partitioning the design space, etc.” (PE1). Several panel members pointed out that engineers not only collaborate with other engineers but also other individuals (e.g., non-engineers, experts from other disciplines): “Engineers need to know how to work with others, laypeople and experts from other disciplines” (EE9). Besides, it was considered engineering as a collective work because engineers require input from “a number of varied stakeholders” (EE8) and learn from one another.

Another participant illuminated the role of collaboration during and after the design process in the following observation:

> Engineering by nature is very collaborative even if they have an individual engineer working on a project, the results of that project are typically shared and then incorporated within other projects and also depending upon the scale of the project you can have engineers working collaboratively. Also, collaboration is very important to the process itself because as the engineers are communicating, they also solve problems, and actually, testing their thought process their solutions, so just the act of collaboration and communicating encompasses the engineering design process. (EEPE2)

Two panel members underlined that there are various roles in an engineering company are taken by people with different expertise and engineers need to work collaboratively with them:

> In general, what a company would do, engage in experts including a mass of people, not just engineers, finance people, salespeople executives, and purchasing people. They build a team; they bring their expertise. This is the best way to apply the process. (EE2)

In the second round, the panel members further justified the collaboration theme by stressing how essential collaboration is in producing designs efficiently as: "A German engineer told me that in general they are all much better trained than those in NA but the superiority of NA engineers is the ability to work more effectively in teams" (EE2).

In Round 2, one panel member (EEP6) suggested merging the themes of communication and collaboration because it was considered that they were related concepts. The themes were retained as distinct entities in Round 3 since both individually had high average ratings in Round 2 (M>4.5).

Another participant cautioned against that the collaboration theme does not mention the collaboration with end-users during the design process in Round 3 as follows: "Collaboration does not capture the client/user/those affected by the problem. Engineers need to be able to communicate and collaborate with these individuals, or their representatives/advocates to really know what they are designing for or what problem they are solving" (EE8). Therefore, the collaboration with end-users to produce designs that satisfy end-users' needs and desires.

Multiple Solutions. This theme, initially indicated by five panel members, coupled with high mean ratings across the last two rounds (Round 2: *M*=4.11; *SD*=.88; Round 3: *M*= 4.13; *SD*= .89). This theme underlined two different meanings. Unlike facts and theories in the field of science, there may be multiple solutions to an engineering problem or multiple ways to solve a problem as one panel member stressed: "In terms of the design process, there can be several right answers, there can be answers that are better or worse" (EE11). In this sense, "engineers are not necessarily thinking that there is one solution or there is one correct way to do that" (EE1). Likewise, another panel member noted that "engineering solutions are not single-valued, different people will come up with different solutions which sometimes can be radically different but equally as effective, and there is no rote method which will lead to a preordained answer" (EEP1). Therefore, "there may be many acceptable designs to solve a problem, each with unique pros/cons" (EEP1). Although engineers may have many alternative solutions at hand, they need to choose "the good enough solution(s)" (EEP6). The second meaning comes into prominence when considering the good enough solutions. The decision on a good enough or satisficing solution is bounded to a specific context. For instance, one panel member argued "context, constraints, and trade-offs, including customer and designer preferences, all affect the final outcome" (EEP1).

In Round 2, one panel member commented that engineers may have multiple solutions at hand; however, engineers should take the time constraints into account during design processes:

> Yes, there are multiple solutions, but it is also important for an engineer to understand the time constraint that comes with their problem. It does benefit an engineer to understand there are multiple, workable solutions, but it does not benefit the engineer to waste time testing all solutions. I see this all too often in my classroom, students will test all solutions and by the time they choose the best one, they are in a time crunch and cannot create the best product with the best decided upon solution. (EEP8)

By the same token, in Round 3, one of the panel members advised more emphasis on the summary "satisficing" solutions that: "Engineers are seeking a good enough solution to a given problem because of constraints on time" (EEP6). The panel member also noted that it is not feasible to identify all possible solutions to a problem and thus "more typically, engineers will settle on the good enough solution, pass that along, and only seek another if the need arises." In light of this, the panel member suggested putting a special emphasis on the notion of "ill-defined solutions".

Modeling. Although this theme initially suggested by three panel members, had high rates across rounds (Round 2: *M*=4.53; *SD*=.7; Round 3: *M*= 4.44; *SD*= .81). Besides physical prototyping, one engineering educator (EEPE8) noted that virtual modeling is an integral part of the design process, especially when building physical prototypes is difficult and expensive. Also, the panel member noted that "the most courses that engineering students take are related to the mathematical/scientific modeling of the physical systems, not on engineering design itself".

The same panel member also underscored the necessity of using virtual prototypes in building high fidelity models and conducting simulations. Besides, the virtual prototypes "improves the quality of the product and gets closer to what the end-user desires." (EEPE8)

One of the panel members considered modeling "vital" to the design process as "design requires predicting the behavior of a system that does not yet exist" (EEP4). Besides, the panel member provided examples for engineering models as follows: "Models include engineering science models, computer models such as finite element models, BIM models, and even the mental models that engineers have. Modeling is also important to the design process, particularly in instances where prototyping is difficult or expensive" (EE4).

Empirical. Fourteen panel members either explicitly or implicitly addressed that engineering designs are developed based on empirical evidence. This theme had high mean ratings across two last rounds (Round 2: *M*=4.37; *SD*=.68; Round 3: *M*= 4.44; *SD*= .81). This theme focuses on the idea that engineers use empirical data to determine the effectiveness of designs as "there is an evaluation; gathering data to test prototypes that are definitely part of the design process" (EE4). One panel member stressed the role of science and math principles in producing empirical data as follows: Engineers "use the principles of science and the predictive capabilities of mathematics to base decisions on data" (EEPE4). Especially when there is no scientific theory to guide design processes, engineers rely on empirical data. One panel member used a historical example to prove his point:

> A historical example of this occurred in the Haber-Bosch [process] creating ammonia the process of creating ammonia. They are creating industrial ammonia and at that time scientific knowledge was not enough. They knew they need a catalyst in order to design the process and they did not know what the catalyst was supposed to be, so they did

> randomly try different stuff to find the catalyst that helps design the process. They basically do empirical sorts of studies. (EEP6)

In engineering, viable solution ideas should be evaluated “objectively in terms of their pros and cons” (PE1). In that sense, using empirical data is necessary since “it is very important for the selected idea to actually be the best alternative” (EE10). Further, sufficient or “successful” engineering designs are achieved through empirically driven tests since engineers “quantify performance. [They] find a concrete way to describe if something is good or bad, better or worse” (EEPE1).

Four panel members considered the empirical aspect of engineering as a norm that the engineering community believes govern design processes. Based on the comments made in the last round, several aspects of this theme were considered as norms. Therefore, engineering designs being empirically-based was viewed as a technical aspect of the engineering design process that illuminates that engineers engage in data collection procedures to determine the effectiveness of engineering design ideas as well as a norm or a value that the engineering community adopts.

Failure-Laden. This theme was proposed by five panel members in the first round and rated as (Round 2: M= 4.11; SD= .81; Round 3: M= 4.19; SD= .83). One panel member described failure as “an inherent feature of the design process” (EEPE1). Another participant also underlined that failure is an integral of the engineering design process in the following observation: “It is rare to get the perfect solution the first time out, failure may have to occur before success is possible” (EE11). Similarly, “an individual who expects to be successful on their first attempt at solving an engineering problem will be severely disappointed” (EEPE1).

One panel member stressed that even though failure is inevitable in the design process, engineers should act in a manner to avoid failures as much as possible:

> Engineers need to be a lot smarter about thinking about failures in the sense that we do it… there will be mistakes, there will be failures. And the idea is to either do small things, small steps, small changes so that failures are small and can be handled or make it so that there are ways for failure to occur without bringing the entire system down, we'd call it redundancy or to avoid progressive collapses. (EEP4)

In this regard, one panel member provided examples which illustrated how a failure in an engineering design process could have severe consequences: "Boeing 737, 381 people died because of the single rule failure, so they are software engineers with the product engineering side if a battery is too hot the phone is blowing up on fire" (EEP3).

Several participants also mentioned the concept of learning from failure and some of the panel members regarded it as an important norm of the engineering community that affects the development of engineering work. Therefore, the theme of learning from failure was subsumed under the category of the values, norms, and rules of the engineering community.

Creative. Ten panel members suggested that creativity is important for innovative ideas as well as artistic aspects of engineering designs (Round 2: *M*= 4.1; *SD*= .78; Round 3: *M*= 4.06; *SD*= .93) as shown in the following observations: "It (engineering) usually involves creating something new: a design, a metaphor for the user, a clever application of the laws of physics, etc." (PE1). Also, it was noted that "with the theoretical knowledge alone, engineers do not think of the artistic (creative) aspects of the design… that leads to innovative ideas" (EEP2). Thus, "engineering is an art because for any real result to come about, you have to think of something absolutely new sometimes and engage in thought processes for students" (EE2).

The engineering problems become more complex that requires more than technical knowledge or experience. To provide solutions to today's global problems that society encounters, the creative ideas in engineering designs are needed as one participant emphasized: "I am seeing more large-scale societal problems that society tackle. The project is larger and turns into a broader impact and we need to be more innovative because we need for it, so engineers should be more innovative" (EEP3). For instance, to solve the problem of global warming, creative insights are needed to design "a storm surge wall in the upper east coast that is going to change things for the better" (EEP3). One of the participants further justified the creative aspect of engineering in Round 2 as follows:

> Facts and data are extremely important, but so is creativity and pushing boundaries. A great engineer in today's world needs to be driven by both facts and data, and the willingness to push into what has not been tried. Doing all of this while making sure they are within time constraints and budget. (EEP8)

Besides, one panel member in Round 2 commented that apprenticeship could promote creativity in the following observation: "Creativity can be improved through apprenticeship to a talented master. It cannot be taught especially by those who purport to teach it, they being often the least creative" (EE2).

The creativity theme was rated in the second round relatively low as compared to the ratings of the other themes (M=4.07, SD= .8). Several of the panel members stated that they rated some of the themes as less important not because they are not important, but rather because the themes may not be applicable for all engineering disciplines:

> I struggled with saying some things were less important than others as these all seem important. In the end, I think my saying something was less important might actually

> reflect that it is needed less often. For example, some engineering projects may not require creativity as previous solutions can be used. (EE8)

Non-linear and Iterative-Reflective. This theme was one of the highest-rated aspects across Round 2 and Round 3 (Round 2: *M*= 4.63; *SD*= .76; Round 3: *M*= 4.63; *SD*= .81). Twenty panel members, in the first round, suggested the inclusion of the iterative nature of the design process that most engineers take for granted but they did not emphasize its importance enough in education (EEPE1). This theme focused on the "inherently circular" (EE11) and non-linear design process. One panel member (EEPE2) noted that after the problem statement, the next important aspect of the design process is the iterative nature of the process. The same panel member explained that iterations are guided mostly by the data obtained from the testing and evaluation phase and iterations (going back in the process) continue "only as far as necessary until the solution succeeds" (PE1).

Engineering design is not linear and iterative because "every design project has unique context and constraints and requires creativity and imagination. Thus, projects will proceed in fits and starts, will require iterations, will produce dead ends, and will encounter unexpected obstacles" (EEP1)

Several panel members underlined that engineering design processes are rarely linear, step-by-step, or formulaic; however, students or novice engineers may need to learn "general rules and guidelines" (EEP6) that govern the design process. The design steps engineers follow are "usually very sequential and relatively easy to identify" (EE9) and thus, the design process is rather "messy" (EE4). As engineers gain more experience, they can go with the design practices which are necessary at a particular moment and "there is more of a flow between the steps" (EE9). Similarly, one panel member stated on this issue as follows:

> Designers will often be jumping back and forth between the tasks more or less continuously. Many people wrongly think that engineering design can be done via some kind of step-by-step recipe. Being a skilled designer does not simply mean internalizing some step-by-step process; rather, it is a matter of knowing which of the activities above makes sense at the moment, and how to execute them well. (EEP6)

Similarly, two participants cautioned to teaching the stages of engineering design processes as distinct entities when they are presented as steps of the design process to young students as follows:

> We teach the design process within our curriculum is actually a six-step design process…however, because of the iterative nature of the design process they all occur simultaneously and sometimes seamlessly taking place, so when we teach it, we break it down for our students because they are young and inexperienced we want to illustrate each one of the steps but when you are a practicing engineer or a practicing problem solver for that matter frequently the steps are occurring at the same time and sometimes you go back and forth so it is not really a linear by step process there are stages and you can go back and forth. (EEPE2)

> While certain activities do tend to precede others, the major tasks that occur during design happen essentially on an ad hoc basis and tasks can occur more or less simultaneously. However, for 12 education novices, I would represent them as distinct entities. (EEP6)

One participant, in that regard, mentioned that presenting students the stages like a linear process, they may tend to think that “these items a checklist of things that must be completed to do a design” (EEP5). Hence, the solution is to make “the design process about the process and not actionable items that can be checked of. It forces them to consider when their design is done--and not rely on getting to the end of the process" (EEP5).

Also, some expert panelists mentioned that for larger and more complex engineering problems, there could be "mini design processes within the overall design process" (EEPE2). One panel member suggested that the iterative nature of the design process is sometimes ignored or misunderstood because they may think that "the first prototype is going to be the final product" and he added: "There is a lot more value after you get your first prototype. You evaluate it, you change it and the debugging is a big part of the engineering process. I think you need to have iteration in design processes" (EE4).

Besides, the iterative design method offers an opportunity for engineers to revise design artifacts to maintain constantly changing customers' needs and desires as one participant stated:

> There are definitely engineers involved in continued support for products. If you keep building something for multiple years and one of the suppliers suddenly does not make a certain part anymore you have to go ahead and maintain that so there is the life cycle aspect of engineer design. (EE4)

Also, engineers are able to sustain the ever-changing needs and problems of society by applying iterative design procedures. Consider the following statement as regards to changing needs of society:

> The iterative nature of the design process, [part of the design process], means that you are going to evaluate the solution and determine if the solution is still valid. Over time, things change as society is not static rather it is very dynamic therefore the solution that was developed at one point in time may not be applicable at a later point in time. Because of

> the iterative nature of the design process, it [the design process] can be readily applied. (EEPE3)

One panel member in Round 1 proposed an “iterative-reflective process” in which “the reflection is what moves the engineer from one iteration to the next--whether it be in a brainstorming stage or a prototyping stage” (EEP5). Therefore, “it is essential for engineers to think over what they have done and determine what they need to do next for a very intentional reason.” (EEP5). Besides, iterations, contrary to common perception, do not start in the design refinement phase but rather iterations along with reflections upon what engineers just did start as early as solution ideas being generated as the panel member suggested.

Due to the iterative method, it was pointed out, however, that “engineering design cannot stop at the select and refine a solution phase” (EE4) since there is always the option to revise and the “desire to constantly innovate and improve” (EEPE1) by means of iterative design, it can be said, “in a sense, a design is never finished” (EEP1). For this reason, it is important that “clear criteria must be set out upfront to judge whether the design goals have been accomplished” (EEP1) One panel member emphasized the benefits and drawback of the iterative design method as follow:

> The desire to constantly improve a design can be a double-edged sword for engineers. On one hand, it drives ever-improving products and processes. On the other, it can cause designs to never get off of the drawing board. Striking a balance between improvement and delivering a product is a constant challenge. (EEPE1)

In Round 2 one of the panel members argued that reflective practice is more appropriate for the field of philosophy than engineering because “engineering practice is inevitably time-constrained” (EE2). In Round 3, the original title was revised as just “iterative” in the light of this comment. On the other hand, two panel members challenged this suggested revision and supported the inclusion of reflective practices in the design process. One of them commented on that as follows: “The reflection occurs after the project is completed. The reflection is done to examine what you did in order to possibly learn from it” (EEP1). When taken into account the evaluation process based on empirical data, the necessity of the constant comparison of criteria and constraints with the features and the function of the product, and going back to recognize the design failure as well as the advantages of making reflections at the end of the design process in order to learn from design experiences, the reflection becomes a necessary part of the iterative design process, and thereby the decision was to keep the original title.

In the same line of thinking, one panel member in Round 2 suggested possible integration of the themes “empirical” and “failure-laden” into the theme of “iterative-reflective”: “Empirical and failure laden can be wrapped into iterative and reflective. What information are you reflecting on if not empirical evidence and failure?” (EEPE4). The themes were kept as distinct epistemic aspects of engineering due to the high-ranking rate in Round 2 (Empirical: M=4.37; Failure-Laden: M=4.2). On the other hand, as the panel member underlined, it would not be reasonable to ignore the relationships among these three epistemic aspects of engineering. Hence, the decision was to keep the themes as distinct aspects but the relation between them should be acknowledged.

Trade-off Decision Making. This theme initially suggested by six panel members in Round 1, was combined with a high degree of stability across the last two rounds (Round 2: *M*= 4.16; *SD*= .96; Round 3: *M*= 4.25; *SD*= .86). The theme focuses on the idea that engineers do not always have the optimum of each quality. Thus, engineers “must make trade-offs” (EE2). “The goal is to find a design that provides an amount of each of these qualities that we can live with" (EEP1). One of the panel members illustrates this theme with an example:

> Do you want it to be affordable? Or safe? Or locally sourced? Sustainable? Made of gold. Unfortunately, you cannot always have all of these in one end product. Pick your top three criteria (if possible) and design a product around the design criteria. For example, if you want to design a bicycle that is affordable and safe, but made of gold, you may have to give up one of those criteria because "affordable and gold" do not go together. However, affordable, safe, and aluminum do! (EEPE8)

Another participant also exemplified a trade-off decision making for the criteria of economics and sustainability: "Things should last as long as they can, but there is a balance there between cost [economics] and lifelong lifetime [sustainability]. You have got to balance those. You cannot just spend everything. You have got limits" (EEP4).

In round 2, one of the panel members commented on the correction of the summary statement for the theme. Put more specifically, the panel member stated that engineers need to make trade-off decisions not because "we[engineers] cannot have all these qualities" but rather, "we cannot have the optimum of each quality when considered on its own" (EEP1). The panel member made his point by providing an example from his field:

> We must make trade-offs mean we cannot have all these qualities? No, it does not mean that. In fact, if we are successful at producing an airplane, our wing will necessarily be light enough, strong enough, lift-producing enough, drag-reducing enough, and cost-effective enough, because if any of those things is not true, then the airplane won't work. (EEP1)

In the above statement, the panel member pointed out that engineers should pay attention to each quality of designs because they are not independent of each other but rather they all influence one another. Therefore, it is important to have the all qualities to achieve an acceptable, working solution. The difference between the two statements is that "trade-offs are not so much about not getting all the qualities we want, but rather about getting a sufficient amount of all the qualities we want". Hence, the summary statement was revised based on the panel member's justifications.

Socially Embedded. This theme focused on the idea that engineering work is dependent on the social context. It was rated across two rounds as follows: Round 2: *M*= 4.32; *SD*= .82; Round 3: *M*= 4.38; *SD*= .81). This theme covers both client- and organizational-level interactions and societal-level interactions. First, one of the key features of engineering is that engineers need to understand "what [their] customer/end-user needs/wants in a product and [engineers] are designing a product around those needs/wants" (EEPE8).

In the same line of thinking, the panel members addressed that engineers are required to take customers' needs and how they experience the engineering design into consideration as shown in the following statements: "designers seek out what a customer really wants to start to the design process". For instance, "[engineers] want to make sure that they understand that if they are designing it for a child for someone that is older and might not be able to use that product with their hands" (EEP5). Therefore, "thinking about how the user is going to experience the product and when they use this product is important for creating a successful product" (EEP5). Hence, the parameters or values that are integrated into the design is considered around the clients/end-users' needs and desires.

Besides, engineers usually work for larger companies and organizations and they are expected to serve them and integrate their values in their engineering decision-making process. Consider the following statement: "engineers generally work within larger organizations and are expected to serve that organization" (EEP6). Also, the same panel member exemplified this point as: "Certain companies might be interested in sustainability, and engineers working for those companies would have to attend to those values" (EEP6).

This theme also emphasized the relationship between engineering and society. One participant described the main idea underlying this theme that was also inferred from other participants' statements as "engineering and society have been inseparable since before recorded history of engineering" (EEP4). Different types of relationships between engineering and society were identified by thirty-two participants in Round 1. One panel member, for instance, emphasized how engineering shape the community around them as:

> Engineering is more than just the individual who might be sitting in a room off to the side separate that it really is an opportunity for you to take something that you are skilled in and help shape that community around you when and give back to that community. (EE11)

Another panel member stressed the contribution of engineers to the society by solving problems in the following observation: "engineers are problem solvers and in society, there are technical problems, there are social problems, there are ecological problems, there is any number of problems and the design process can be applied to any of those problems now" (EEPE2). Similarly, another panel member underlined the response of engineering to societal problems as follows: "I am seeing more large-scale societal problems that society tackles. The project is larger and turns into a broader impact and we are happened to be more innovative because we need for it, so engineers should be more innovative" (EEP3)

One panel member associated this relationship with the motivations underlying works of engineers as follows: "Engineering is motivated by improvement of society and that engineering takes in perspectives from a vast range of society identified issues within society and tries to create an improved situation positive outcomes through what it can offer" (EE5)

Several participants portrayed the reciprocal relationship between engineering and society. Consider the following statement:

> Society is also what influences the direction in some ways of what engineering does. They always have to be cognizant of what society is to have better engineering and when you have that better engineering because they need to look at society, they are now making society better. (EE11)

In the same line of thinking, another participant also stated: "In reality, it should be kind of this cycle: Society informs what engineers do, engineers contribute to society, and society reacts and reforms what engineers do and we continue in this loop that leads a better place" (EE5).

Another important point concerning the transformational impact of engineering designs on society was voiced by several panel members as follows: "We engineered the entire planet not always in a good way but we as humans affected the entire planet" (EEP4). Another point was made concerning the adverse effects or side effects that technology has brought to society in the following observation:

> Engineers interact with society in a lot of ways. We have the ability to change the world based on what we are doing, what I am seeing in some of the fields, for instance, global

> warming, engineering maybe not directly cause global warming but there are the side effects going on right now in the world with different storms being larger than they have been. (EE3)

One panel member described engineering as a "high impact discipline" that has direct effects on society: "In engineering there are real consequences, if you make a mistake, maybe the lives could be affected. For instance, 381 people died because of the single rule failure [in Boeing 737]" (EEP3). By the same token, another panel member underscored the human factor in the engineering design as follows: "you have to know the science, you have to know math to be a good engineer but you also have to know how it is going to impact everyone you have to understand that engineering is going to have a long-term impact may be immediately maybe not,…,so engineers also have to know the long-term effects as well as the short-term effects of a product" (EEPE8).

It was also highlighted by the panel member how politics have impacts on the engineering works:

> The laws (state & provincial) governing the practice of engineering are very well established but politicians regularly override them for expediency & personal profit. The Challenger brittle seal problems & the current Boeing 737 max 800 where layers of software patches formed a deadly scab. In addition, the attitude sensor freezing problem is not new. The Boeing engineers failed to note an earlier Airbus 300 disaster due to the same cause. (EE2).

It is worth noting that even though themes of the stages of the engineering design process were classified separately from the other aspects, this does not mean that the knowledge being used and ethical values being considered in engineering are distinct entities. The knowledge, as well as ethical values, are incorporated into each phase of the engineering design process which means that engineering problems should be defined, and solution ideas should be tested and evaluated from “scientific, safety, economic, and social perspectives” (EEPE7). One panel member also exemplified this point in the following description:

> [Engineers need to] understand the context of the solution (e.g., the community in which something will be built), the needs and wants of the stakeholders for whom the solution will affect (e.g., the diverse perspectives of the community members), and the implications of solutions (e.g., disproportionate benefits to community members) in order to design an effective solution. (EE8)

Three panel members in Round 2 voiced their concerns about the summary statement of this theme. One of them found the phrase “interaction between engineering and society” problematic as it may suggest “engineering and society are separate things”. The panel member thought that the language used in the summary statement “tends to demarcate engineering from society conveys the wrong idea.” In this sense, the panel member argued that “engineers aren’t some alien beings working on top of a mountain and throwing down their creations to society below” but rather “there is a transactional relationship where society puts things and engineers integrated…It is just a manifestation of society and it is embedded, it is one manifestation of humans do in like a lot of manifestations of what humans do”. Therefore, the panel member recommended a revision of the statement as follows:

> I would rather say that engineers and engineering have a role to play in society. That role is shaped by societal forces, both internal and external to engineering. In turn, the outputs of engineering activity have cascading effects on other societal activities and relationships. (EEP1)

Another panel member similarly suggested for revision for this theme as follows:

> "Socially Embedded" is important, but I think the summary contains some language that is unnecessarily value-laden. The statement that "engineers create solutions that are useful to society or provide society with some new convenience or power" assumes that everything that engineers produce is an unqualified good. That assumption really does not hold up to scrutiny. I would strongly suggest that normative language such as that be kept out of this. (EEP6)

Even though this aspect of engineering may reflect the practices in some fields of engineering, it may be not applicable to all engineers. On the other hand, the decision with regard to whether it should be addressed in K-12 engineering education was further discussed with the K-12 science and engineering educators during the focus group meeting.

Being Methodical. This theme conveys the idea that each phase of the engineering design process is important to design solutions. There are real but distinct undesirable consequences of performing carelessly or inadequately any step of the design process. For instance, one panel member identified the difficulties that may be encountered when design processes are not carried out carefully as the following statement illustrates:

> If the problem definition step is shortchanged, then you can wind up with a mismatch between the problem and the solution. If the concept generation step is shortchanged, you might miss one or more good solutions. If the detailed design step is shortchanged, you might wind up with design errors, suboptimal materials, and parts, or incompatible subsystems. If modeling and/or prototyping is shortchanged, you might miss real-world behaviors that are not adequately captured in conceptual and theoretical analyses. (EEP1)

Similarly, another panel member emphasized being methodical as an important aspect of the engineering design process since missing any step of the design process would result in solutions which do not work as they are intended to do:

> Be methodical. Rushing through the process will usually lead to either boring designs that look like existing products, or it will lead to novel ideas that do not work due to some fatal theoretical flaws in the design. A design that does not have a prototype and does not get evaluated is missing the biggest and most difficult part of the process. Coming up with ideas is easy, getting ideas that actually work is "real" engineering. (EE4)

While the aspect of Being Methodical received support by six panel members in Round 1, its mean rating was less than 4 (M=3.84) and the standard deviation was found to be higher than 1 (SD=1.21) which indicates low consensus among the panel members. Therefore, this theme was not included in the final list. In this sense, one participant commented in Round 2 regarding this theme as follows: “One is either inclined to be methodical and/or compromises prone by nature. Its desirability can be mentioned but do not expect people, like the tiger, to change stripes” (EE2) which indicates that being methodical does not always reflect the true nature of the engineering design.

Uncertainty. In Round 1, four experts considered uncertainty and ambiguity as an important aspect of engineering. This theme underlined the idea that uncertainty may infuse many aspects of the design process as:

> Design requirements are often subject to interpretation; the expertise and knowledge needed to solve a design problem may not always be known in advance because they may depend on the nature of the proposed solution; constraints and requirements may change

during the course of a project; uncertainty may pervade many aspects of a project. (EEP1)

Several of these participants argued that engineers make decisions with limited knowledge and information: “the knowledge is based around the need to make decisions under uncertainty” (EEP4), and thus, “there is always limit in what engineers do” (EEP6) In this case, they used heuristics to determine whether designs work.

On the other hand, although the mean rating of this theme was higher than 4 in Round 2 (*M*=4.05), the standard deviation was found to be greater than 1 (*SD*=1.03>1), indicating that there was a low consensus among the panel members. For that reason, this theme was not included in Round 3. In this regard, one panel member argued “If you cannot make decisions in the light of incomplete knowledge you are dead.” (EE2) Hence, it was inferred that there is some degree of uncertainty in some engineering design projects, but it is hard to generalize the theme to the engineering discipline. One panel member stated, in relation to uncertainty: “The ability to make prototypes strongly affects the level of uncertainty that the engineer must make decisions under” (EEP4). Therefore, the idea behind this theme was integrated into the theme of idea evaluation since as the panel member underlined, prototyping reduces the level of uncertainty.

Table 4.3
Key aspects of the engineering design and descriptive statistics in Round 2 and Round 3

Epistemic Aspect Title	Round 2			Round 3			Stability (%)
	Mean	Mode	*SD*	Mean	Mode	*SD*	
Communication	4.84	5	.37	4.63	5	.5	68.75
Collaboration	4.63	5	.6	4.56	5	.63	68.75
Multiple Solutions	4.11	4	.88	4.13	5	.89	68.75
Modeling	4.53	5	.7	4.44	5	.81	68.75
Empirical	4.37	5	.68	4.44	5	.81	75
Failure-laden	4.11	4	.81	4.19	5	.83	87.5
Creative	4.1	4	.78	4.06	5	.93	75
Non-linear and Iterative	4.63	5	.76	4.63	5	.81	68.75

Trade-off Decision Making	4.16	5	.96	4.25	5	.86	87.5
Socially-Embedded	4.32	5	.82	4.38	5	.81	81.25
Being Methodical	3.84	5	1.21	N/R[a]	N/R[a]	N/R[a]	-
Uncertainty	4.05	5	1.03	N/R[a]	N/R[a]	N/R[a]	-

Note: Consensus criteria: Mean > 4; Standards Deviation <1

Stability criterion: a change of one-third or less in the ratings (or >66.67)

[a] The themes of Being Methodical and Uncertainty were not included in Round 3 since their ratings and/or standard deviations did not meet the consensus criteria.

Values, Norms, and Rules of the Engineering Community

Consider the following statement describing engineering as a distinct discipline which as its own values and standards, etc.: “Engineering is widely considered to be a profession, which connotes a special category of occupation that is distinguished by have special shared norms, and values along with perhaps a shared idea” (EEP1).

Most panel members pointed out the ethical and moral values that are (should be) intrinsic to engineering disciplines: “ethical norms -- most professions, including engineering, have ethical codes that either prescribe certain types of unwanted conduct or, more generally, promote certain types of aspirational conduct” (EEP1). It was inferred that ethical and moral codes and responsibilities constitute an important part of the engineering profession.

In this sense, one of the panel members cautioned against the generalizations of ethical and moral codes to all engineering community:

> Ethics and morals are fluid and are not written in stone. It is important to ask the question of where the morals and ethics are coming from; which country, which religion, which laws, etc. Once you know the source of the ethical line of thinking, you can be more confident in your following of those ethics and morals. (EEP8)

As the panel member voiced, it should be acknowledged that ethical and moral codes could vary from place to place and time to time depends on the societal, cultural, political, and organizational factors. on the other hand, safety, integrity, and honoring intellectual property were considered as important values and norms of the engineering community by the panel members. See Table 4.4 for the ratings of each theme under this category.

Safety. One of the themes that had the highest uptake by the panel members was the theme of safety. Almost all panel members stated the most paramount value at play during the design process was safety and engineers should engage in the ethical decision-making process carefully. The theme had a higher degree of stability and consensus across the rounds (Round 2: *M*= 4.68; *SD*= .58; Round 3: *M*= 4.69; *SD*= .6).

The main idea that this theme conveys is designing technologies that do not harm end-users, society, and the environment. One of the panel members described safety as a core value of the engineering discipline as follows: “The engineering community has generally enshrined safety as a core value. Safety here basically means that designed technologies should not cause harm to their users, consumers, etc.” (EEP6). Similarly, another panel member underlined the care dimension of the engineering discipline in the following statement: “engineering design requires ethical decision-making and care for anything affected by an engineering design including humans, animals, plants, air quality, etc.” (EE8)

One of the panel members who was in the field of computer engineering mentioned the issues related to computer programs such as privacy issues as follows: “Ethics become very predominant in our field lately because of all the data privacy concerns that are out there. The one thing I notice that has come about our ethics and morals in the practice of creating codes” (EEP3). The panel member also touched on how especially new technological devices have an immediate influence on society and how important to consider the safety issues associated with electronic devices and artificial intelligence as follows:

> Now, it is just what we do immediately affects what happens around the world. I think they (engineers) need to be aware of the impact in which their product, knowledge, and skills are going to impact quickly. There is a convergence of both data and people, and we are doing cross cultures but also our devices are able to transcend the location, space, and time. We should be aware of is the importance of artificial intelligence and whether it will have to either improve or become a detriment to society. (EEP3)

Likewise, engineers need to be aware of the potential risks that their designs carry: "Engineers need to be more aware of the risk involved in anything. The nuclear engineering field is the first one considering it" (EEPE7). In order to assess potential safety and health risks that engineering design poses, engineers are required to use risk analysis: "Engineers also need to understand safety and risk analysis. A solution is often sought in order to reduce risk and improve safety, but the solution often entails risk as well. An understanding of risk tradeoffs is necessary" (EEPE7). However, sometimes engineers do not carefully assess the consequences of engineering designs that could result in detrimental effects. For instance, "engineers built a road in a village connecting the village to its water source….However, as a consequence of that road, there were actually traffic accidents that increased the mortality rate in the village" (EE5).

Although safety was identified as a core value of engineering, sometimes there are tensions between ethical values and the values and activity of engineering organizations as mentioned by several participants. One panel member voiced this tension in a way that engineers working in organizations and companies are expected to serve those institutions; however, sometimes the conflict arises when organizations violate the ethical values such as the core value of safety for the sake of fulfilling a certain function of the design:

> Engineers generally work within larger organizations and are expected to serve that organization. They are generally not encouraged to question the overall motives or trajectories of that organization. They are expected to, as per #1 (functionality), develop technologies that work (according to whatever definition the organization sets). This is clearly sometimes in tension with #2 (safety). Some scholars regard this as a kind of amorality. (EEP6)

Along with the same line of thinking, another panel member stressed that engineers make trade-offs between costs and safety; however, when engineers make trade-off decisions on safety, they need to be careful, otherwise, it may result in severe consequences: "Boeing plane, some of the characteristics were neglected to speed up production so that it could be marketed faster, so they neglected to some of the training that involves for the Pilots and those are clearly matter of ethics" (EEPE7).

Integrity. This theme focuses on the dimensions of honesty, trustworthiness, and being transparent and moral responsibilities of engineers. The theme was considered important or very important for the engineering discipline across the last two rounds (Round 2: *M*=4.53; *SD*=.96; Round 3: *M*= 4.5; *SD*= .63). One of the panel members indicated engineers need "to respect what the data lead to so you need to make sure that you are being honest and transparent" (EE11). The main idea is that engineers should have a transparent manner, especially for safety issues when performing the design process. Consider the following statement:

> The engineering community expects that you will always act in a trustworthy and transparent manner when it comes to safety, engineering calculations, and ethics. If there

> is ever a doubt about the calculations or decisions, one should err on the side of caution and not go ahead with a decision until the calculations can be double-checked. (EEPE8)

Similarly, another panel member stated: “Honesty about the process, specifications, safety, and objective analysis are important aspects of engineering. Engineers will not sacrifice safety to save on costs” (EE9) However, honesty and transparency may not be sufficient to detect the risks that designs could pose to the public. In this case, engineers need to accept “fallibility” as an integral part of the design and “create ways for engineers to objectively check their work, or each other's” (PE1)

In relation to engineers’ morals, one panel member discussed the importance of both personal and professional values that play a role in engineering decision making as engineering design have “real-world effects” as follows:

> Engineering decisions change the world in some sense, changes what people do and how they behave and how they go about their business and when I make those design decisions based on whatever values I have in my head, in my heart, both personal values and values that have been instilled in me through my professional socialization and so, those values get embedded into technologies the engineers develop because they have real-world effects (EEP1)

This point is worth emphasizing since the core values such as safety should not be considered as just an ethical or legal obligation governing the engineering profession, but also as a moral responsibility of engineers beyond their legal responsibilities to protect end-users and public safety and health. This value gains more importance when considering the unintentional consequences that engineering designs bring. In this regard, one of the panel members highlighted “engineering designs affect how people are interacting with one another, so there are sometimes unintentional impacts just because people are interacting with the engineered world. So often it is impossible to get away from the subtle influences of that" (EE4). On that account, it is essential for the engineering profession to have both moral and ethical responsibility as one panel member stressed in the following statement:

> We have a professional responsibility to let people know about it (if the design is unsafe to use)… I think integrity is very high on the list of values for engineers. You do not get very far as an engineer if you are not honest and then we fall back to things like facts and data. We respect people's judgment but if the facts of data show that their judgment was wrong and typically those people need to change [their designs]. (EEPE1)

It seems that most panel members concurred that "all decisions should be made in an ethical manner, with human and public safety as the first and foremost concern" (EEPE8). However, several panel members stressed that the engineering community sometimes tackles the ethical and moral issues. One panel member, for instance, mentioned the ethical dilemmas that engineers sometimes experience in making decisions. The panel member, in this sense, emphasized the importance of taking responsibility for possible intended consequences as follows:

> The ethical dilemma comes into effect when engineers do not completely or correctly apply the engineering process to consider aspects of a design that might have detrimental effects. This is also challenging when considering the concept of unintended consequences. That said, it is the engineers' responsibility to make a good faith effort to consider the implications of their design. (EEPE2)

Ethical dilemmas related to the safety become very complicated for engineers working in some organizations as the following example indicates: "Engineers working for some military contractor, given the task design of the weapon, you can design the weapon very efficiently but the question should I design this weapon; is that really a good thing that needs to be designing." (EEP6). The panel member also pointed out the ongoing discussion in the engineering community regarding the moral value judgments of engineers:

> But there is a lot of controversy over the question of is that (whether, for instance, designing a weapon) really falls in the realm of moral decision making for engineers. There is a growing number of people in the engineering profession starting to realize we need to focus more on those sorts of questions, so when the moral and ethical questions come in depends on "Who You Are", what moral questions you need to choose to engage with it at minimum.

The panel member also added that the engineering community should consider the responsibility as their own: "So, we need to think about what are the possible outcomes that we should think about but traditionally questions have not been answered by the engineering profession, but there are now shifts occurring."

Also, another participant indicated an example to point out the necessity of engineers' ethical responsibility when they conflict with the interests of companies for which they are working: "There is a company out there you work for polluting a river or there is a car designed inappropriately, and dangerous to use it. engineers have the ethical responsibility to address that issue in some way or another" (EE3).

In the same token, two of the panel members used a historical case (Boeing 737 plane) to demonstrate what happens if the engineers' role is minimized in the engineering decision-making process. Consider the following example regarding this example:

> If looking at the Boeing plane, some of the characteristics were neglected in order to speed up production and speed up the plane so that it could be marketed faster so they neglected some of the training that involves for the Pilots and those clearly matter of ethics. Maybe that is more on the management level not on the level of the engineer, but the low level of the engineer has to be involved with it because it is the entire team. (EEPE7)

Other panel member used the same example to stress engineers' ethical and moral responsibilities to speak up in order to prevent engineering failures:

> Engineers need to be very ethical about not letting others convince them that what they believe is correct from an engineering standpoint; should be done or should not be done. The Boeing 737 issue is a good example. The Challenger failure is another good example. So that is to a certain extent safety. But it is really the value of being ethical and not giving in to reasons you do not believe. You really think it should not be done, you really need to stand up as much as possible. (EEP4)

One of the panel members indicated the necessary actions an engineer should take as "following the spirit of the design process with fidelity, thoroughly evaluating the products of the design process with special consideration for any unintended consequences" (EEPE1). However, it seems that the expression "performing the design process with fidelity" led to ambiguity around the theme. To be more specific, the panel member expressed concerns about the possible confusion between the terms of fidelity and integrity in Round 3 as follows:

> I struggled with connecting following the design process with integrity and design process with fidelity. These seem to be two separate things. For example, I can envision an engineer following the design process with a high degree of integrity but not strictly

> adhere to the process, or with less fidelity. The opposite could be true too. The first scenario, high integrity but less than high fidelity, I could understand how that might be the case in a particular situation but the opposite, low integrity but high fidelity does not seem right at all. (EEPE2)

It appears that “fidelity” could suggest being methodical in the engineering design process. Therefore, the term “fidelity” was replaced with integrity in the final summary statement.

Another issue raised regarding placing extra emphasis on the responsibility of engineers that they take for the possible risks that technologies pose. One panel member (EEP6) disagreed with the inclusion of being “sensitive to risks associated with the technologies being developed”. He suggested the mention of objective measures for risks: “engineers tend to adhere to objective standards of safety, integrity, and what have you... and tend not to go much farther than that.” To illustrate his point of view, he provided an example:

> An engineer designing a missile guidance system will make sure that the system does not produce errors that result in the deaths of any operators. On the other hand, though, the whole point of a missile guidance system is to kill people... not the engineer's problem, though. In short: what does it mean to have a safe missile or a safe bomb? (EEP6)

This side of the engineering discipline is worthy of consideration; however, no further revisions had not been made at this point. The decision was taken in the light of suggestions that the expert panel of the focus group including science and engineering educators provided.

Honoring Intellectual Property. This theme was initially considered as a dimension of the theme of Integrity; however, in Round 2 one of the panel members (EEP6) suggested that honoring intellectual property should have been regarded as a distinct theme since its importance to the engineering discipline. Therefore, this theme was presented as a distinct entity in Round 3. Even though this theme was addressed by only two panel members in Round 2, it received support in the last round (Round 3: *M*= 4.38; *SD*= .72).

One panel member pointed out that although this is enforced by intellectual property laws, “but that does not diminish the importance of adherence.” On that account, it is the responsibility of engineers to make sure they properly attribute the contributions of others. Normally, “The legal remedies typically only come into focus when designs develop into a marketable product”. However, it is important that “the same guidelines should be applied, however, before designs become commercially viable” (EEPE2).

The participant also advocated that there should be “strict adherence to rules governing intellectual property rights and ensuring that all those involved in the process are properly and appropriately recognized”. Hence, not just the marketing process, engineers should evaluate the efforts of the other throughout the engineering design process.

Functionality. The importance of the functionality of engineering designs was underscored by four panel members in Round 1 and remained important across the last two rounds (Round 2: *M*=4.47; *SD*=.77; Round 3: *M*= 4.5; *SD*= .73). This theme indicates that “engineering design is concerned with the function”, “what determines which option is successful is functionality” (EE4) as “Engineering designs should function as it needs to fulfill its purpose. If they do not do what they were intended to do, they have failed” (EEP1). One panel described the theme as a “pretty substantial value of engineers regarding designed technologies” since “the most important question regarding technology is whether it WORKS” (EEP6). He also noted that engineers need to determine what “works” mean: “the meaning of works is not predetermined and must be constructed by the engineers. Engineers think about working in very technical terms. Things need to mechanically function according to the laws of physics, for instance." Therefore, it can be inferred that the meaning of "works" is unique to each engineering design. Also, another panel member who viewed functionality as one of the big values of engineering stated: "I think in the end it is about the making sure it works like whatever you are working, whatever product or whatever company you are working with, in the end, I think engineers want something that works" (EE4).

One of the panel members wished to include in the summary statement the mention of forms of engineering designs along with functions in Round 2: "A customer wants something that works, but form follows function is not an acceptable way to view engineering anymore. Form and function should be thought of on the same level if you want the most effective and efficient design" (EEP8).

On the other hand, two panel members in Round 3, objected to the inclusion of form as a pervasive value in engineering designs: "Ask the question if you could only have one, form or function, most rational people would choose function. When form becomes important it automatically becomes part of the functionality" (EEP1). For that reason, the form of designs was not regarded as important as the functionality in the final statement.

In that regard, another panel member reminded the dual nature of engineering designs as the following excerpts indicate:

> Every design has two natures, its "form" and its "function". The "function" is a description of what we want a design to do. The "form" is a physical description of an artifact (what size, shape, material, the arrangement of parts, etc.). The design process is the process of trying to match form to function, but as is indicated by the "multi-valued" feature [of engineering designs], there is no one-to-one mapping between form and

> function. Each form can have many functions and each function can take many forms. (EEP1)

In the above statement, the panel member also challenged with the concept of "form follows function". He made a technical distinction between form and function of engineering designs and considered engineering designs as dual-natured which represents the relation between form and function of engineering designs.

One panel member (EEP1) in Round 3, recommended the integration of the values of effectiveness and efficiency as important ways to assess the functionality of engineering artifacts. The outcome was the decision to integrate these two values in this theme.

Economic Considerations. Economic considerations including designing cost-effective and affordable products were discussed by seven panel members in Round 1 and had relatively high ratings across two rounds (Round 2: *M*=4.22; *SD*=.79; Round 3: *M*= 4.19; *SD*= .92). It was emphasized that engineers should take into consideration the economy "as the design needs to meet economic requirements" (EEPE7) and "provide feasible solutions as well as good solutions" (EE3). Accordingly, engineers focus on "the most optimal solution. There must be many alternatives, they have to choose the most suitable one for society and the economy" (EEP2). Likewise, one of the panel members also emphasized the importance of the affordability of a product for clients as follows: "We are attempting to provide the client with a technically sound solution to their problem which will be safe for the public and economically acceptable to the client" (EEPE5).

One engineering educator mentioned the necessity for engineering students to examine the affordability and market values of their designs as follows:

> The economics of the products they need to consider and also what is going to be the life cycle of this product, what is going to be the market for this project; does it have a market that is going to support it or what they are designing is something that no one can afford (EEP5)

In the first round, one of the panel members argued that depending on the engineering designs, the cost-effectiveness of designs could be sometimes given less consideration as compared to the other values. As the following example that the panel member provided shows:

> I believe that this varies depending on the problem being addressed (norms and values in engineering) Example being that if I am designing a brake system for a car I would want one that is safe, cost-effective, reliable and easy to repair. If I am rebuilding a road I am looking at safety and meeting the needs of the community. While cost could be an issue, it is lower on the list than for a new car system. (EE3)

On the other hand, several panel members worried that the summary statement of "Although its importance varies depending on the problem being addressed, the cost-effectiveness of engineering design is an important value in engineering" did not represent the reality. One panel member, for instance, commented as follows "I am not sure this is a good way to characterize it. Economics is always important - either someone is willing to pay for it, or it does not get done!" (EEP1). By the same token, another panel member asserted "economics is always in play. We cannot ignore that reality" (EE11). Hence, the summary statement was revised in light of the panel members' comments.

Two panel members discussed that it is important to ensure the balance between cost-effectiveness and sustainability is important for engineering design as follows:

> [Designs] should not be too costly and they should not affect the environment as well. Designs should last as long as they can, but there should be a balance there between cost and lifelong sustainability almost does not mean anything unless it is thought about in terms of both costs, because you cannot just spend everything. (EEP4)

In round 3, one panel member wished to include in the theme mention of the factors that may have influences on how economic considerations are handled in the design process:

> What represents an economical engineering solution in one scenario may not be economical in another. While at the time of design, economics must certainly be considered, it is not an enduring measure. Ultimately the marketplace will make that decision if competition and free-market forces are allowed to decide which design will prevail. (EEPE2)

It seems that the market values are important factors that need to be considered, together with the budget of engineering design projects are important elements that engineers should take into account as other panel members suggested: “Economics is always important - either someone is willing to pay for it, or it does not get done!” (EEP1) Also, engineers should be “aware of the commercial market” (EEP3), “what is going to be the market for this project, does it have a market that is going to support it or what are we designing something that no one can afford” (EEP5)

In the third round, one of the panel members advised against the use of the term “optimal” for engineering solutions. He contended that engineers are working towards the “sufficient” or “good enough” solutions, not the optimal solutions because “if there are most optimal solutions, why are products ALWAYS steadily improved upon over time?” (EEP1).

Even though the consensus was reached for this theme across Round 2 and 3, the stability criterion was not achieved for this theme, thereby excluding from the final list.

Desire to Serve Humanity. This theme was put forward as an important value in engineering discipline by nine panel members in Round 1. This theme reflects the "human-centered designs" (EE7) and "designing for people, for humanity" (e.g., EE3, EE4, EE5). One panel member suggested science and math skills are not enough to be a good engineer, the desire to serve humanity is an important value that engineers should possess in the following justification:

> You are really good at math you are really good at science you should be an engineer with the idea that it is only those skills that make you today a good engineer…the desire to improve people's quality of life [is a] huge impact that engineers have that is not always acknowledged in that career choice that it is too heavily weighted on that skill set then on those other pieces. (EE11)

Another panel member who is in the field of civil engineering described the desire to serve humanity as a rule of the engineering discipline: "They have rules, for civil engineers, the first rule is everything you do is for serving humanity, serving society and people, that means something needs to be done by law." (EE3)

It was also suggested by a panel member that engineers put society at the center of their work: "We construct for society in order to improve in order to make things better, easier, faster, safer. I think that you always have to be cognizant of what society needs is to have a better engineering design" (EE11). Similarly, another panel member emphasized, "Each engineer is serving society by solving problems of importance to elements within society" (EEPE5). One panel member claimed that the desire to serve humanity is what drives engineers to do their work as follows: “Engineering is motivated by improvement of society and that engineering takes in perspectives from a vast range of society identifies issues within society and tries to create an improved situation positive outcome through what it can offer” (EE5).

Designing for the greater good was another dimension of this theme that was taken into consideration by two panel members as a crucial value of engineering. One participant, for instance, asserted: “Rules and values of the engineering community are to better the world and leave the world in a better place than you found it. Engineering tries to make things better for the earth and the people that reside here” (EE1). Similarly, another one stated: “I believe that when engineers make decisions, they are making it for the greater good not just to design a product or make it look pretty. They are thinking about how it is going to affect everyone all around” (EEPE8). Also, one of the panel members highlighted the necessity of these kinds of projects for engineering education: “By incorporating local community members or local engineering industry students are able to get different perspectives that guide them through the engineering design process of thinking what the local community needs and how to better serve my community” (EE1).

Besides, one of the panel members criticized some of the trends within the engineering community:

> A lot of engineers have concern about global problems…There are places in Africa where engineers installed clean water systems three times and they just keep breaking and so it is really just a band-aid. We are not fixing problems; we are kind of creating problems in ways. There is a desire to help like global citizens, but I do not think we are really very good at it (EEP5).

These panel members seemed to believe the desire to serve humanity to be crucial to the entire engineering disciplines; however, several other panel members expressed concerns about the desire to serve humanity being the core value of all engineering disciplines in Round 2. One panel member, for instance, reminded engineers working in profit-driven companies and claimed that although this value is “certainly an aspirational value of profession at large, as given in the vision statements of engineering professional organizations, most engineering is done by private companies seeking profits by creating products and technologies that people want” (EEP1). The panel member also touched upon the difference in the intention of “making the world a better place” and building “technologies people want" as follows: “Many people often rationalize that just because people want a technology, that it might provide them with some new convenience or power, that it by definition has made the world a better place. This is a highly contestable proposition”. In a similar way, another panel member underlined that engineers serve for their employers and thus, the desire to serve humanity does not accurately reflect engineers’ routine works: “Desire to serve humanity is an aspiration goal and sounds nice, but I severely question whether that value is a meaningful one in the day-to-day work of engineering. Engineers typically serve their employers, like most professionals” (EEP6). Along with the same line of thinking, one panel member discussed the other desires that engineers bring into the design process as follows:

> I am thinking about the desire to serve humanity. Where would you fit the engineering designs that are purely creative and out-of-the-box? For example, when Elon Musk put a Tesla in space, it wasn't serving humanity but the other things that Musk has developed with his company are engineering designs and I think that these creative inventions are also an aspect of engineering. (EE7)

As the participants argued, engineering designs are created not only to solve human problems and meet clients'/customers' needs but also to build creative solutions that may enable them to gain new convenience or power. As one of the panel members discusses, it is debatable whether the latter purpose is related to serving humanity or not but it is an important aspect of engineering that reflects the nature of engineering discipline (EEP1). The qualitative data was further supported by the quantitative one. Even though this theme had a high rating greater than the cut-off point in Round 2 (M=4.11>4.00), the standard deviation for this theme was found to be higher than 1 (SD=1.24), demonstrating a low consensus among the panel members, thereby excluding from the final list presented in Round 3.

Sustainability. In Round 1, four panel members identified sustainability as an important value in engineering designs. One panel member, for instance, suggested the inclusion of sustainability due to possible environmental impact of engineering designs as follows: "Engineers need to think about sustainability and how, say a technological product, is developed and used in a way that does not harm the environment and society" (EEPE8). In this sense, it is very important that materials you know you want to locally source things, so you want to think about sustainability considering the environmental impacts and a lot of that. Another panel member found the description of the theme vague and to address this issue, he reframed the summary statement as follows:

> Engineers consider environmental impacts and sustainability in their work. Finding ways to mitigate the stress put on the environment by human resource consumption and waste production is an increasingly important responsibility for engineers in order to help ensure a viable future for society. (EEP1)

However, it seems that several panel members did not agree with the inclusion of this theme as a prevalent value in engineering in Round 2. For instance, consider the following statement:

> Certain companies might be interested in sustainability, and engineers working for those companies would have to attend to those values. But I would say that it is demonstrably untrue that sustainability is a pervasive value in the engineering profession. If it were, there would be no engineers working for the fossil fuel industry. (EEP6)

Another panel member illustrated his view with an example: "Sustainability is now denied to us…, new ones (refrigerators) die minutes after the warranty expires. Engineers could change this, but they seldom have the tools, authority, or inclination to do so; witness Challenger seals & 800 MAX software" (EE2).

The quantitative data further reflected the different views on this theme. In round 2, even though the theme was rated above the cut-off point (M=4.32), it seemed that the consensus was not reached regarding the inclusion of this theme as a prevalent value in engineering (SD=1.0). Hence, *Sustainability* theme was not included in the final list.

Table 4.4

Values, norms and rules of the engineering community and descriptive statistics in Round 2 and Round 3

Epistemic Aspect Title	Round 2			Round 3			Stability (%)
	Mean	Mode	*SD*	Mean	Mode	*SD*	
Safety	4.68	5	.58	4.69	5	.6	75
Integrity	4.53	5	.96	4.5	5	.63	68.75
Honoring Intellectual Property	N/R[a]	N/R[a]	N/R[a]	4.38	5	.72	-
Functionality	4.47	5	.77	4.5	5	.73	87.5
Economic Considerations	4.22	5	.79	4.19	5	.92	62.5
Desire to Serve Humanity	4.11	5	1.24	N/R[b]	N/R[b]	N/R[b]	-
Sustainability	4.32	5	1.0	N/R[b]	N/R[b]	N/R[b]	-

Note: Consensus criteria: Mean > 4; Standards Deviation <1

Stability criterion: a change of one-third or less in the ratings (or >66.67)

[a] The theme of *Honoring Intellectual Property* was given a separate category in Round 3 based on the comments

[b] The themes of *Desire to serve Humanity* and *Sustainability* were not included in Round 3 since their ratings and/or standard deviations did not meet the consensus criteria.

Empirical Norms. This theme was also regarded as an important norm of the engineering community which highlights that engineers "rely on facts and data. There is no place for hearsay or opinions. Facts and data always rule the day" (EEPE1). Besides, another panel member also challenged with the dogmatic views in engineering to point out the importance of empirical evidence as follows:

> A lot of people in the engineering community do not subscribe to dogmatic views. I see that it is very difficult to believe certain things unless they are there to be tested and proven.… For instance, empirical norms should be given emphasis in the engineering community in case someone may be able to disregard research or factual information because they were able to see a human side. (EEP8)

In the same vein, another panel member stressed that engineers may need to rely on empirical data to ensure whether the design is designed adhering to ethical values as follows:

> We have a professional responsibility to let people know about it (if the design is unsafe to use)…If you are not honest and then we fall back to things like facts and data. We respect people's judgments but if the facts of data show that their judgment was wrong and typically those people need to change [their designs]. (EEPE1)

One panel member (EEP6) touched upon the standards of evidence that engineers use to evaluate whether or not a design technology works. He noted that it is difficult to describe what those standards exactly are since "they will vary by context". However, "generally speaking, the evidence used in engineering needs to at least be consistent with accepted theoretical knowledge, consistent with standard practice, obtained through generally-agreed-upon methods, etc." The panel member also mentioned what counts as evidence in the engineering discipline "is, naturally, socially determined." and that depends on the values that engineers have.

Learning from Failure. As mentioned earlier, the theme of learning from failure was considered as a norm that engineers should adopt to contribute to the development of the knowledge base of the engineering discipline. Several panel members stressed the value of learning from failures for engineering discipline as follows: "Failure (if learned from) can pave the way to success" (EE11). One panel member borrowed the words of Mark Twain to illustrate experience, especially if it comes from failures in engineering designs, could be invaluable for the engineering discipline: "Good judgment comes from experience and experience comes from bad judgment and engineering experience" (EEP4).

Other panel members explained how the design failures contribute to future engineering work in the discipline: "Engineering knowledge advances by learning from failures (e.g., Tacoma Narrows)" (EEP4). Likewise, consider the following justifications for the importance of learning from failure in the engineering work: "Sometimes figuring out what does not work is just as important as figuring out what does work and sometimes when you make a mistake you figure out something else" (EEPE8); "I know that is how a lot of inventions have come about is just from mistakes that were made" (EEPE8); "Success tells you very little, but failures show that you have exceeded the limits of the design" (EEP4). Also, another panel member suggested that learning from design failures be critically examined:

> Learning from failures that engineers have to recognize. We learn from failure and if we just want to hide it and push it away and ignore it we are missing out on an opportunity to

> make something in the future better because we look at what that failure was and learned from it. (EE11)

Three panel members considered the learning from failure as one of the important norms that engineers should accept, understand and adopt because failures are an integral part of engineering: “nothing guarantees no failures, and then learn from them.” (EEP4)

Communication Norms. As discussed earlier, communication was also suggested as a norm of the engineering community as it was suggested by several panel members. As a norm, the theme focuses on the formal and informal communication norms. The communication norms include “standard jargon and terminology, standard formats for engineering drawings and schematics, standard modes of writing and reporting technical information, etc.” (EEP1) The panel member also noted the function of these communication norms as: “Such norms allow for the efficient and accurate transmission of technical information with a minimum of confusion and misinterpretation”

Several other participants also emphasized the necessity of “documenting both the process and the solution (e.g., “detailed records of discussions, decisions, thought processes, etc.”) throughout the process” (PE1). Also, one of the panel members mentioned the importance of communication as: “whether it would be spoken, written, or visual, all those of things are hugely important to engineers” (EEP4) and elaborated its role both prototypical and non-prototypical system designs in terms of the role of communication as follows:

> The typical example [for prototypical systems] I use is the automobile engine. An engineer can design it, modify it or do something with it and then have it built so that a technician can build it for them, therefore, they [engineers] have to communicate with the technicians. That includes drawings, calculations, actual blueprints, and things like that.

> In non-prototypical design, [engineers] just design and build it, so there is going to be interaction among engineers and there is also going to be some effort to make sure whatever that design is correct, there is an independent checkup, peer-review

Another panel member pointed out the importance of written and verbal communication in working in teams and working with clients in the following observation:

> There is so much teamwork and there is so much understanding of the customers' need and being able to explain things in a clear concise manner to people who are not necessarily technical engineers to need to have a command both verbal communication and written communication and they also just need to be able to listen and gather information from especially customers or users down the road to understand what they need and not kind of sit there and assume what they need. (EEP5)

Demarcation between science and engineering. Even though the difference between the science and engineering disciplines were addressed by several panel members, this theme was not included in the list of the epistemic aspects of engineering as it does not represent an epistemic aspect pertaining to the engineering discipline. On the other hand, since it was considered as an important topic for pre-college science and engineering education, the participants' opinions with regard to the distinction between these two disciplines were included in this section.

In general, the practical side of engineering was considered as the main feature that differentiates engineering from science. Consider the following statement: "Engineering is more about trying to create a social change and societal improvement through technology" (EE5). Another panel member addressed the practicality in engineering to make it clear how engineering is different from science: "engineering is a field aiming at working towards making a practical item, scientists understand why things work the way they do, engineering applies the fundamental science engineering applies into something more practical" (EEPE7). Also, consider the following observation which identifies the differences:

> Science is extending knowledge. It can go on forever. All we do is extend the knowledge. We can always learn more. In engineering you have to make decisions, you cannot keep learning more, you have to go to take a chance to build something. (EEP4)

One participant focused on their aims as: "scientists seek to form an understanding of the world as it is, engineers seek to use their understanding to design an artificial world that benefits humanity" (EE4). Also, one panel member emphasized the defining feature of the engineering discipline as: "the engineering design process challenges what exists and obviates the reasons that the desired solution does not already exist" (EEPE4). Another participant made the distinction to illustrate the important aspects of engineering that separate it from other disciplines as follows:

> Engineers are not usually in the business of discovering new scientific principles; rather how they can be used to create useful things. -Design means, thinking about such things as modularity, usability, human factors, and other aspects that distinguish, for example, a merely "working" but complex or unintuitive solution from one that is understandable, maintainable, etc. (EE11)

The necessity of technological knowledge was also identified as a distinct feature of the engineering discipline as it was evident in one panel member's account: "The whole reason engineers have specializations is because they need to understand certain technological systems …Even someone with extensive mathematical and scientific knowledge would be utterly bewildered by most of the technological systems in the modern world" (EEP6). Scientists often are not interested in how technologies work but rather they use them as a means to explore the natural world whereas engineers need technological understanding in their work. Several panel members underlined the reasons why that knowledge is necessary for engineering: “the whole reason engineers have specializations is because they need to understand certain technological systems in order to engage in meaningful design” (EEP6) and another participant thought that technological knowledge is important “to choose the appropriate path in which to solve the problem” (EEP8). Also, one panel member stated this knowledge is required to design the next technologies as follows:

> They do not just use a tool as a tool--they seek to understand why a tool works the way it does…it is only once [they] get to this level of understanding that [they] can figure out how [they] might do it differently. (EEP5)

It was stressed that there is a symbiotic relationship between science and engineers as “science can push engineering, but engineering can also produce better science in a lot of ways.” For instance, “engineers are working on the lab equipment and that can enable better scientific research or a jump in scientific research and then that scientific research can then have effects on engineering itself like what product development is available” (EEP5).

Another difference was noted regarding the degree of generalizability of engineering design and scientific knowledge as one of the panel members indicated in the following statement: “scientific knowledge is more along the lines of the scientific process and a little more generalized whereas the engineering design is a little bit more specific to the technical tasks at hand” (EE5)

The economic and social aspects of engineering were also highlighted to elucidate the distinction between science and engineering as follows: “Science does not spend as much time considering the economic implications of what they are doing because, in the end, they are not trying to sell a product" and engineers "create something that is going to be useful to me or some else or society. The pure pursuit of understanding and knowledge rests with science but the creating of tools that will better society is engineering" (EEP5).

The panel members stressed the importance of the human factor in the engineering activities as follows:

> Engineering is different from science because…it is taking the human factors…you have to know the science; you have to know math to be a good engineer, but you also have to know how it (the design) is going to impact everyone. (EEPE8)

In this regard, the direct consequences of engineering were discussed to differentiate engineering from science. Unlike end-products produced in other disciplines, "in engineering, there are real consequences, if you make a mistake, maybe the lives could be affected… It is a high impact discipline" (EEP3) and "engineering is going to have a long-term impact may be immediately maybe not,…,so engineers also have to know the long-term effects as well as the short-term effects of a product" (EEPE8). Therefore, as opposed to science, engineers need to consider "who is going to be using it [their designs] at the end because [they] need to know where [they] are going at the end before you even get to start" (EEPE8). Furthermore, they need to think "about the consequences that their products may have (i.e. safety, sustainability, etc.)" (EEPE8).

Besides, engineers use any kind of knowledge that aids them in solving problems and making decisions, unlike science: "engineers essentially use whatever knowledge they have to do design. That means engineers use both, any scientific knowledge that works for them, any engineering science knowledge works for them, any empirical knowledge works for them"

(EEP4). In that regard, as opposed to science, engineering is, in a sense, a pragmatics field where engineers “have to take everything that they have learned and have to be able to make the best decision” (EEPE8).

Similar to what the bounded aspect of engineering puts forth, engineers deal with multiple solutions as well as multiple ways and approaches to solve a problem. On the other hand, the discipline of science is guided by universality to produce the best available explanation. Further, contrary to the discipline of science which seeks out universal theories and laws, engineering design within a specific context in which engineers attempt to achieve a satisficing solution to a particular problem.

Contrary to common perception, engineering needs a wealthy of knowledge, just as a science since “a strong foundation in content [knowledge], [from] a diverse range of knowledge that spans various topics, allows an engineer to develop novel solutions” (EE7); however, engineering is more about “the necessity of being able to utilize that knowledge (factual information) when needed and when appropriate” (PE3).

Lastly, the engineering community has to integrate contextual values in order to satisfy human needs and desires. Therefore, one can say that engineering discipline can be considered as a profession driven by both core and contextual values.

Summary of the Results of the Delphi Study

In round 1, twenty-eight epistemic aspects of engineering were identified. Each aspect was, then, rated on a 5-point Likert scale, ranging from not at all important to very important in Round 2. After this round, only the epistemic aspects with a mean value of >4 and a standard deviation value of <1, indicating a high consensus level among the panel members were kept for the third and last round. Therefore, for the Delphi study, the consensus criterion was determined as at least 75%, rating each epistemic aspect as 4 or 5, indicating important or very important on the 5-point Likert scale. The data obtained from Round 2 indicated that the mean ratings of twenty-four themes ranged from 3.73 for *Experiential Knowledge* to 4.87 for *Communication* as shown in Table 4.5. The mean values of twenty-four aspects were greater than 4 and above. Two themes, *Identification of Design Specifications and Requirements,* and *Honoring intellectual property* were given a separate category based on the suggested revisions for Round 3. The stability criterion was determined as a change of one-third or less in the ratings of the panel members across two rounds, Round 2 and 3. The stability criterion was not achieved for only the theme of *Economic Considerations,* which reducing the total number of themes to twenty-three. Table 4.5 also illustrates the final epistemic aspects of engineering with descriptive statistics for each epistemic rated in the third and final round. As seen in the table, each epistemic aspect met the stability criterion.

Table 4.5
Descriptive statistics for each epistemic rated in the third and final round

Epistemic Aspects		Mean	Mode	*SD*	Rank Order Round 2	Rank Order Round 3
Knowledge Base for Engineering	Scientific knowledge	4.56[c]	5	.63	5[bc]	4[c]
	Mathematic knowledge	4.5[bc]	5	.63	8[b]	5[bc]
	Technological knowledge	4.56[c]	5	.63	11[b]	4[c]
	Engineering knowledge	4.69[c]	5	.6	4[b]	1[c]
The Stages of Engineering Design	Problem definition	4.69[c]	5	.6	2	1[c]
	Identification of Design Specifications	4.56[c]	5	.63	N/R[a]	4[c]
	Idea Generation	4.38[b]	4	.62	16[b]	9[b]
	Idea Evaluation	4.44[b]	5	.73	13	7[b]

	Design Refinement	4.56[c]	5	.63	7	4[c]
Key Aspects of Engineering Design	Communication	4.63[b]	5	.5	1	2[b]
	Collaboration	4.56[c]	5	.63	5[bc]	4[c]
	Multiple solutions	4.13	5	.89	20	14
	Modeling	4.44[bc]	5	.81	9[b]	8[bc]
	Empirical	4.44[bc]	5	.81	14	8[cb]
	Failure-laden	4.19	5	.83	19[b]	13
	Creative	4.06	5	.93	21	15
	Non-Linear and Iterative	4.63[b]	5	.81	6[b]	3[b]
	Trade-off decision making	4.25	5	.86	18	12
	Socially-embedded	4.38[b]	5	.81	15[b]	11[b]
Values and Norms of the Engineering Community	Safety	4.69[c]	5	.6	3	1[c]
	Integrity	4.5[cb]	5	.63	10[b]	5[cb]
	Honoring intellectual property	4.38[b]	5	.72	N/R[a]	10[b]
	Functionality	4.5[b]	5	.73	12[b]	6[b]

Note: Epistemic aspects rated based on a 5-Likert scale (1= Strongly Disagree…5= Strongly Agree

[a] Aspects were not rated in the second round until they were suggested inclusion as a separate.

[b] Aspects with same mean ratings were ordered starting with the smallest standard deviation

[c] Aspects with same with same mean ratings and standard deviation were assigned with same ranking number

Variance in the Expert Panel Ratings

The analysis of the degree of variability in the mean ratings given by the subgroups of the Delphi expert panel with regard to the epistemic aspects of engineering was performed. The subgroups of the expert panel comprised engineering/science educators (EE), engineering/science educators who were also researchers in the area of philosophy and history of engineering and technology (EEP), engineering educator/practicing engineers (EEPE). In Round 3, only one practicing engineer (PE1) filled out the questionnaire. Therefore, the participant (PE1) was not included in the analysis of variability.

The aim of this analysis was to explore the variance within the subgroups of the expert panel as well as investigate any significant differences between the mean values of the subgroups of the panel, in other words, whether the mean values, for example of the engineering educators significantly differed from those of, for example, the researcher in the area of philosophy of engineering.

Variability within the Subgroups. On the basis of the mean ratings gathered in Round 3, the epistemic aspects assigned the highest importance by each subgroup were listed below:

Engineering Education (EE) (*N*= 5): *Engineering Knowledge (Mean=4.8)*

Engineering/Science Education/Philosophy and History of Engineering/Technology (EEP) (*N*= 6): Mathematic Knowledge, Technological Knowledge, *Problem Definition, Safety, and Functionality* (*Mean= 4.83*)

Engineering Educators/Practicing Engineers (EEPE) (*N*= 4): *Problem Definition, Communication, Iterative-Reflective* (*Mean =5*)

As the above mean ratings indicate, the epistemic aspects of *Problem Definition* (EEP, EEPE) were rated as very important by two subgroups of the expert panel. The ratings of the other epistemic aspects varied across subgroups. These differences could be attributable to their different professional experiences (see Table 4.6).

Table 4.6

Analysis of variance in ratings of each group for Round 3 aspects

Epistemic Aspects		Variance			Mean Group Responses		
		EE	EEP	EEPE	EE	EEP	EEPE
Knowledge Base for Engineering	Scientific knowledge	.8	.27	.33	4.4	4.67	4.5
	Mathematic knowledge	.5	.17	.33	4.0	4.83	4.5
	Technological knowledge	.3	.17	.25	4.4	4.83	4.25
	Engineering knowledge	.2	.7	.25	4.8	4.5	4.75
The Stages of Engineering Design	Problem definition	.7	.17	.0	4.2	4.83	5.0
	Identification of Design Specifications	.7	.27	.25	4.2	4.67	4.75
	Idea generation	.7	.3	.25	4.2	4.5	4.25
	Idea Evaluation	.3	.7	.67	4.6	4.5	4.0
	Design Refinement	.8	.55	.5	4.4	4.5	4.75
Key Aspects of Engineering Design	Communication	.3	.3	.0	4.6	4.5	5.0
	Collaboration	.3	.7	.25	4.6	4.5	4.75
	Modeling	.8	.67	.1	4.4	4.33	4.5
	Multiple solutions	1.0	.97	.92	4.0	4.17	4.25
	Empirical	1.2	.27	.92	4.2	4.67	4.25
	Failure-laden	1.0	.57	1.0	4.0	4.17	4.5
	Iterative-reflective	1.2	.67	.0	4.2	4.67	5.0
	Creative	1.0	.97	1.0	4.0	3.83	4.5
	Trade-off decision making	1.2	.27	.92	3.8	4.47	4.25
	Socially-embedded	1.0	.27	.92	4.0	4.67	4.25
Values and Norms of the Engineering Community	Do not harm (Safety)	.8	.17	.25	4.4	4.83	4.75
	Integrity	.8	.3	.33	4.4	4.5	4.5
	Honoring intellectual property	1.2	.3	.33	4.2	4.5	4.5
	Functionality	.7	.17	.92	4.2	4.83	4.25

To investigate whether the variance within the groups was large, the criterion proposed by Osborne et al. (2003) was used. That is, the variance point above 1.5 on the Likert scale was considered as a large variance within the subgroups. On the basis of this criterion, it seems that there was no large variance (<1.5 points of variance) within subgroups with respect to all epistemic aspects of engineering. The mean ratings among Engineering Education (EE) demonstrate relatively large variances for the aspects of engineering for nineteen aspects (1.5>… >.1 points of variance). Thus, this group indicates a relatively heterogeneous group in the overall expert panel. On the other hand, the subgroups of Engineering Education/Philosophy (EEP) and Engineering Education/Practicing Engineering (EEPE) were the relatively more homogenous group in the panel as the mean rating of these groups illustrated relatively low variance for most of the aspects. Within the EE group, the large variance was found with regard to the aspect of *Empirical*, *Iterative Reflective*, *Trade-off* and *Honoring Intellectual Property* (points of variance= 1.2).

On the other hand, it has to be noted that these findings should be interpreted when taking into consideration the small sample size especially for the subgroups of EE (*N*=5). In this subgroup, only 5 panel members out of 11 total members of the EE subgroup participated in the last round. Even though it was hard to reach a conclusion with the small sample size, the relatively large variance among the subgroup of EE may be attributable to the diverse engineering fields the members belong to (environmental engineering, civil engineering, aerospace engineering, mechanics engineering, science education etc.).

Variability between Groups. The analysis of variance was employed for each twenty-three epistemic aspects of engineering to explore any significant differences between the mean ratings of the subgroups of the expert panel, considering twenty-three aspects as the dependent variable and the subgroups of the Delphi panel as the independent variable. Table 4.7 indicates that no significant difference was observed between any subgroup.

Once again, with such a small sample size, significant differences would be observed only if "the range around any one mean is both small and widely separated from another group" (Osborne et al., 2003, p. 711). On the other hand, the results do not show any significance based on the analysis of Scheffé's post-hoc test, indicating consensus across the subgroups.

Table 4.7
Results from the ANOVA test subgroup comparison for each theme

Epistemic Aspects		Degrees of Freedom	*F*	*P*
Knowledge Base for Engineering	Scientific knowledge	2	.22	.81
	Mathematic knowledge	2	2.97	.09
	Technological knowledge	2	2.05	.17
	Engineering knowledge	2	0.34	.72
The Stages of Engineering Design	Problem definition	2	2.81	.1
	Identification of Design Specifications	2	1.04	.38
	Idea Generation	2	0.34	.72
	Idea Evaluation	2	0.81	.47
	Design Refinement	2	0.31	.74
Key Aspects of Engineering Design	Communication	2	1.41	.28
	Collaboration	2	0.17	.85
	Modeling	2	0.04	.96
	Multiple solutions	2	0.08	.93
	Empirical	2	0.48	.63
	Failure-laden	2	0.35	.72
	Iterative-reflective	2	1.08	.37
	Creative	2	0.56	.59
	Trade-off decision making	2	1.39	.29
	Socially-embedded	2	0.93	.42
Values and Norms of the Engineering Community	Safety	2	0.69	.52
	Integrity	2	0.04	.97
	Honoring intellectual property	2	0.25	.79
	Functionality	2	1.27	.32

Focus Group Meeting

During the focus group meeting, the findings from the Delphi study were discussed with the group of K-12 science and engineering educators (KSEE) who have at least three years of experience in teaching and/or researching in K-12 engineering education.

Several suggestions were made regarding whether and how the themes identified in the Delphi study should be integrated into K-12 science and engineering education and learning progression of the themes. With regard to the knowledge base of engineering, one panel member suggested considering engineering knowledge as an overarching theme that encompasses all other epistemic aspects of engineering as the other aspects are somehow embedded in the theme of engineering knowledge.

With regard to the stages of the engineering design process, one of the panel members commented that the use of language for the stages of the engineering design process could be confusing as follows: “you can have many ideas leading to one design but it is not clear whether the idea refinement is about the design ideas going to design refinement or it is the design itself” (KSEE1). In that regard, it is not explicit that it is the idea for a design or the design itself that goes through the refinement phase. To avoid the ambiguity that the label causes, the titles of the stages of the engineering design process were revised as the design refinement. For this reason, the title of this stage, “idea refinement”, was replaced with “design refinement”.

Another panel member recommended taking into account “social and ethical considerations” into the stages of the design as “it seems problematic that the design processes being described purely from a technical standpoint and talking about them as a side issue, instead of embedding them in the design process” (KSEE2). The panel member also noted that in design lessons, teachers’ implementations, or engineering education standards, there is a lack of discussions and attempts to integrate these issues in the design process. Another panel member added that these issues should be addressed in the design specifications (KSEE1). For the question of whether the social and ethical issues should also be started to integrate into the elementary level education or should be limited to middle or high school education, one panel member asserted "I think you should start with elementary because if you try and educate, you can build these habits minds at the beginning" (KSEE3). The panel member underlined that it would not be practical to ask older students to start considering these issues. Also, the panel member underlined the child moral development stages as regards the inclusion of the ethical and moral considerations as follows:

> Older students like middle and high school students are in the class of psychological development stages where they may be beyond justice and fairness or hyper-focused on justice and fairness issues, but little kids are always concerned about what is fair and what is right and who is left out and who is not. (KSEE3)

Accordingly, the decision on the practical implications related to those issues was to incorporate the social and ethical issues associated with particular engineering problems in the design process starting at the elementary level. Besides, the panel member discussed the importance of addressing those issues especially in the problem definition phase for student learning: "The first iteration of the problem definition potentially changes as they think about ethical and social implications and so, the problem definition evolves as they move through. Also, they can generate ideas and brainstorm ideas considering these issues". On the same issue, one panel member claimed that "the issue here is related to the nature of the task itself that dictates the complexity of these considerations" (KSEE2). Hence, the level of complexity of engineering problems along with their ethical and social implications should be taken into consideration when making decisions regarding the learning progression.

Another participant argued with regard to the implication of the stages of the engineering design process for teacher education: “If you especially end up using these [themes] to guide PD [professional development] programs with teachers you might want to have the interactions with different stakeholders more explicit in this part” (KSEE4).

As regards the key aspects of engineering design, one panel member found the wording “reflection” vague as she thinks it might not reflect what it was actually meant: “this may be not aligned with what engineers meant with the word reflection” (KSEE2). On the same issue, another panel member discussed that “reflective” could be a broad aspect that connects to and include other themes in the following observation:

> When we take a look at the engineering units and lessons, most of them have some kind of visual representations or engineering models and there is no one single engineering design process people are going through. This aspect I think emphasizes whether it is circular or linear whatever it is, there is no one single path, like a zigzag, the actual process is a much more complicated process. I think the reflective part is related to that there are multiple solutions, empirical and failure-laden nature of engineering. I think reflectivity encompasses all these themes, it may be not related to one aspect, most aspects in this section make the whole process reflective, not just one piece. (KSEE5)

Besides, one panel member addressed that the issue is more about the rationale behind the wording “reflectivity” as follows:

> One of the things we have struggled with our teachers is trying to get them to press their students for a design rationale, so why are they making certain decisions. It is difficult to

> have them connect science and mathematics back to that rationale. But to me, that is the word that is missing but it is something with that rationale or evidence-based or something along those lines that might provide a deeper meaning for the word reflective (KSEE6).

It appears that the panel members suggested that for the practical implications of the practice of making reflections, reflection not be conceived as mere making reflections on what students go through during the design process, but rather, they need to critically examine what engineering decisions they make, how they use science and math knowledge to make decisions and solve problems, how well their end product fulfill the design requirements that they established at the beginning of the design, what kind of failures that they encounter and what they did to eliminate them, how they use evidence to guide the process, etc. In short, it is important for educators to indicate students “what engineers are intuitively doing, …, [so that] in the same way our students do so” (KSEE2).

One panel member (KSEE3) mentioned the inherent connection between the practice of reflection and communication and how this practice should be used to not only help students learn from their engineering design experiences but also improve their communication abilities as follows: “Reflection is a lot of times connected to the communication ability of students”. At this point, the panel member emphasized the different communication abilities and thus, reflection abilities that students have across grade levels in the following justification:

> When we are thinking about grade bands or how we expect somebody to do iteration-reflection, then if we are going to put into context of having teachers to teach kids how to do it and then assess them. We have to connect it to the human development scale and their cognitive abilities to do a particular task. The way a first grader communicates is

> different than the way the eighth grader communicates and that is different than the way a twelfth grader communicates. So, we need to teach kids how we want them to communicate in this particular context, but it is still dependent upon the vocabulary that they have and how they build an argument. So, iterative means being reflective. If I am looking at it from a student perspective and saying it broke, we have to do it again. That is not going to get them anywhere if we are really trying to unpack their experiences.

Hence, it was evident, then, that learning from reflections requires a certain level of communication skills that could vary across grade-bands and it is the teachers' responsibility to introduce and teach students how to communicate and in turn, how to effectively make reflections upon their design experiences to learn from them.

A panel member (KSEE5) proposed that rather than limiting the reflection practices to one aspect but making the whole process reflective by explicitly integrating all epistemic aspects of engineering in the activity. To be more specific, the panel member argued that before, during or after an engineering design activity, students should be given an opportunity to discuss and reflect upon what they go through in the light of all key aspects of the engineering design process:

> When we do engineering in design units and activities in our classrooms, it is not just the activity that we do during the activity and maybe before, after or during the design activity, we need to take time to talk about what people come up with different ideas to address the same problems or same issues and they created multiple solutions for the same idea, how they were created during the process and to what extent they used the empirical data to test their design ideas and what they did during design; if they had a failure, how they were able to fix or overcome those kinds of failures. I think taking time

> to talk about these aspects within the context of their own engineering design experience makes the whole process a reflective process so…before, during and after the engineering design activity making these aspects an objective of our engineering design unit and then taking time to talk about these ideas by giving them certain questions in a way that they reflect on what they have done from the perspectives of these aspects makes the whole process reflective.

In regard to the theme of the socially embedded nature of engineering, it was suggested that the use of language could lead to misunderstandings regarding the connection between engineering and society. One panel member pointed out that the use of language in explaining the interconnectedness of engineering with society could depict engineers as an outsider working outside of society as follows:

> The language is speaking is that engineers are outside of society and they are fixing a problem that society has as if they do not participate. Somebody brings up a problem, they just go and they fix it and they come back into their lab or their office and move on (KSEE3).

She also noted that the type of the communication with the clients and stakeholder, in that sense, plays a significant role in shaping an inaccurate representation of this connection between society and engineering in the following statement:

> That plays a role in communication and there are certain types of directions of communication with the client and stakeholders. That is not necessarily a conversation, we collect data, we do design, we come back and we do again, it is sort of transactional, it is not communal, they are not participating as a team to solve a problem with the people that it might affect or it is affected. (KSEE3)

In that respect, another participant (KSEE1) partially challenged this observation about the communication and the relationship between engineers and clients or stakeholders by asserting that:

> But is not that how a lot of engineering [works]. It may not be how we wanted to be, but when a company comes and says [that] they have got a million dollars to design the next widget that fixes machines and engineers need to go back, push back upon them. [Engineers] have to help shape the problem but for the design specifications, it is not open to so much conversation. So, I think some problems are societal but there is a lot of engineering that they are told to focus on this little teeny tiny piece and the technical specifications and the budget. [They] do not care how [engineers] think about the problem, [they] just need the thing and that is why [they] are paying. I think we want to be a little bit careful that we also do not pretend as if [this was not the reality in engineering].

Then, the panel member recommended portraying of the true nature of engineering in the classrooms in such a way that engineers not always serving humanity but they are working in companies and they need to serve them and adopt their values as their own in order to prepare K-12 students what they will encounter when they start to work as an engineer in a company as follows:

> One of the things I hear from a lot of engineers is that they are concerned because they are starting to see students who think they are going to do all these steps; they are going to have all this control but [that's not the case]. Their job in the workforce is to test five thousand Springs and tell them [whoever they work for] which one is strongest. I am not saying we want to do that in K-12 but I think we need to balance this idea that the client

> oftentimes tells engineers what to do if they have the money…There are ways even do more collaborative works but I think we want to be careful that we do not send a bunch of students out thinking that they are going to go work in a company and most of these engineering workplaces and have a lot of say in how this goes down because they are hired and then, they do the work they tell you to do. They need to do what they hire to do, or they need to quit. I think we do have to recognize that they are in society in some ways as a citizen but in their jobs, they may be forced to do things in other kinds of ways.

In the same way, one panel member of the Delphi study regarded serving organizations or companies for which engineers work: “Engineers generally work within larger organizations and are expected to serve that organization. They are generally not encouraged to question the overall motives or trajectories of that organization” (EEP6).

It seems that the panel members thought that as regards the practical and pedagogical implications of this theme, there should be a balance between what ideally engineering activity should be and what the real engineering activity that engineers most of the time engage in is. Put it differently, as the panel member highlighted that although there are societal problems that engineers tackle and for that, they need to participate in more collaborative works but there is this another side of the engineering work in which engineers have little control over the design process and do what their clients or stakeholders or whoever hire them want them to do. In this regard, another panel member discussed the actual purpose of integrating engineering into K-12 education that may necessitate different pedagogical implications: “That comes back down the broader purpose of why we want to integrate engineering into k-12. Are we trying to prepare them to be engineers or are we asking them to have a broader engineering STEM literacy?”

(KSEE2). In response to this, the panel member clarified her viewpoint on this issue, and she stated:

> But you may need some of each. I think we have to recognize we need both. I am not saying that we do not have that social part but I think what I am hearing now from a lot of schools of engineering is they are coming in with fairly distorted views of what they just enrolled in and so I am not saying do not do socially conscious but I do not think we can take everything out of engineering that is the practice of engineering or much of it. (KSEE1)

The panel member (KSEE2), then suggested, addressing the engineering subfields such as civil engineering, mechanical engineering or environmental engineering differently in terms of the impacts that these subdisciplines have on society as follows:

> Maybe at another level, it can be addressed; some items (the epistemic aspects) depend on what kind of engineering you are talking about. if I am a mechanical engineer and I am designing this widget and I have got very narrow technical parameters and odds are that widget is not going to kill anybody but if I am a civil engineer,…, work[ing] on a rail system and [I need to think] that has huge social and environmental implications that are way broader than what kind of trap do I put down and how fastest the train go.

In the end, it seemed that two panel members (KSEE1 and KSEE2) reached a consensus on covering both sides of engineering discipline, but concurrently, addressing the responsibilities that engineers have on society and environment regardless of how much control they have over the design activities:

> I certainly think even if you do not have a saying, you should still have a responsibility to recognize how your device interacts with society, so kids should be thinking about what

> they are doing in some larger context especially in K-12 and then the degree to which other specifications are and how important other specifications are. But I think you should always be thinking outward about why we are doing this and for whom and for what purpose. (KSEE1)

One of the panel members argued that the role of creativity in the engineering design process could be used to balance two purposes of engineering education in K-12 education in the following suggestion:

> The way of striking that balance might be that creativity piece. Creativity is important but if we are going to support teachers' abilities to support both the development of engineering literacy but also some future engineers, those are both important purposes and students' funds of knowledge in our classrooms and how they apply who they are in those that design work is certainly relevant to the work that engineers do. The insights that they have even when it might be a part of a plane or type of ceramic or whatever. The creativity element and its relationship to subjectivity (multiple solutions). If we can get teachers to think about why that is important in authentic engineering and to make connections to why that is really important for just teaching kids in general that might be a good space to try to have a little balance. (KSEE4)

One panel member (KSEE1) recommended a revision for the title, key aspects of the engineering design process as these aspects could be considered as the practices that engineering engage in not necessarily during the design process. Put it differently, some of the practices such as reflection or aspects such as socially embedded are not just linked to the engineering design process. Thus, the decision was to change the title as the key aspects of engineering design.

In regard to the values, norms, and rules of the engineering community, one panel member (KSEE2) wished a revision for the title, *Safety*, since it does not encompass what the summary statement conveys. She added that it may sound like safety for the working conditions such as wearing goggles or hard toe shoes, but it has a broader meaning, it means “do not harm”. Several suggestions were discussed including “do not harm”, “considerations of collateral damage” or “engineering equivalent of the Hippocratic oath” (KSEE3). The decision was to replace the word “safety” with “Do not harm” (KSEE2).

One of the panel members (KSEE1) suggesting using “should” as a verb rather than “must” or “need” for the ethical and moral values because “those qualifying words (need or must) I think a lot of these are aspirational and unfortunately not always followed, we know we should do but we do not always do that; however, I think standardizing [the verbs] would help to communicate that all of these (values)”.

During the focus group meeting, the themes including *Uncertainty*, *Being Methodical*, *Sustainability* and *Desire to Serve Humanity* were excluded from the final list of the epistemic aspects as their mean values were not so low even though they did not meet the consensus criteria (Mean>4; Standard Deviation <1). When the researcher clarified why sustainability and desire to serve humanity were dropped from the list based on the comments of several panel members which included discussions on these values not being pervasive values in engineering given that some engineering companies or organizations do put more value on profit rather than serving humanity and/or sustainability. In response to this, one panel member advocated the inclusion of these themes in the list as “I think this (companies giving priority to profit) is an important reason to put this in because we are trying to educate future engineers and maybe these (values) tweak things a little bit” (KSEE2). Another issue regarding these four themes was related to the connections of the values of sustainability and desire to serve humanity to the value of safety or do not harm and socially embeddedness aspect. One panel member (KSEE1), for example, recommended the integration of the value of desire to serve humanity into the value of safety as some of the elements discussed in the summary statement of the desire to value theme are captured by the value of safety. On the other hand, another panel member opposed this integration as she considered them different. Specifically, she stated: "do not harm one is about not going to kill someone whereas the desire to serve humanity is broader about what kinds of projects do we choose to work on. They are related but I see them as different" (KSEE2). Besides, the panel member further justified the inclusion of the desire to serve humanity theme into the list as it can be a motivation to consider engineering as a career option especially for minority students:

> With work I have done with gender equity particularly middle school students and students of color if we want to attract different people so not white males to the profession, things like sustainability and helping communities and improve lives are really important and so from an education perspective I find it very unfortunate that they were being not included. (KSEE2)

However, another panel member (KSEE1) partially challenged this viewpoint as follows:

> I agree with what the panel member (KSEE2) said about how we get [students] interested. I believe the national academy is changing the conversation and talking about changing the world around us. [But] I am wondering if there is a way to frame it differently because I do think for some students, it [desire to serve humanity] is the driving factors. But many students of other types do not want to interact with humans, they are very entrenched by numbers or designs and many of those end up in engineering.

> So, framing it in a way that it could be both humanities but also changing the world allows them to pick and choose about helping people or is about something that they think is cool technology that may change the world. But they do not care about people, so if we put something like in that to make sure that we are not excluding some [students] by biasing it and usually I bias toward the helping side. But if this is the framework for everybody, I think we need to be realistic in how we frame it so that people can see themselves in their aspirations.

On the same issue, another panel member (KSEE3) justified the idea of presenting tension in the engineering discipline. To be more specific, she suggested addressing both sides of engineering including the values of serving humanity and serving organization in the following statement:

> We want engineers to want to do certain things but they are working within the context of a company [where profit is important] so, …, what the goals in the epistemic aspect of an engineer or engineers do as an individual and the part that they play in a bigger system. For example, maybe they make a decision based on not harm and we have got examples from the past about engineers saying they needed more boats on the Titanic and somebody else said no more than these [boats] because it does not look good and this is what we are going to pay for. So, if we are going to educate, we have to educate students about that tension because that is why some of them stop or leave and maybe it is because there is some maturity about every job has in an institution and they have to do something that they do not necessarily agree with or they do not want to do. But to put the burden on an individual that they are responsible for all of this and then not give [them] space. At least shed light on the fact that they may decide, or they might want to do this. We care

> about sustainability and we made these decisions and we took into consideration. But the person who signs the check or the [another person] at the top says no, we are not doing that, so how the process that engineers go through that they make and the goals that they have might not fit in the culture and society with which they are placed it.

This tension between engineers' own values or ethical values and the values of engineering organizations can sometimes arise as one of the panel members of the Delphi study indicated: because engineers are expected to work towards organizations' values and desires, sometimes "they are expected to, as per #1 (functionality), develop technologies that work (according to whatever definition the organization sets). This is clearly sometimes in tension with #2 (safety). Some scholars regard this as a kind of "amorality" (EEP6). The panel member illustrated his point with the following example: "engineers working for some military contractor, given the task design of the weapon…the question should I design this weapon; is that really a good thing that needs to be designed". The same panel member also touched upon the changing trends in the engineering community: "I think there is a growing number of people engineering profession starting to realize we need to focus more on those sorts of questions, so when the moral and ethical questions come in depends on Who You Are" (EEP6) This is an important point that may have pedagogical implications in K-12 education.

In regard to the value of sustainability, one panel member also advocated the inclusion of the sustainability value into the list and suggested even if students are more interested in technical aspects of engineering, they still need to think about designs, taking into consideration the sustainability factor. The panel member explained this point with an example as follows:

> From a female perspective, environmental consideration is probably what becomes aspirational. But thinking about sustainability, [it] is important even if [engineers] are

> designing a widget and they are a number and a widget engineer, thinking about how I am going to use this metal. Some of it is an engineering decision and some of it is related to where it is coming from. [For instance], materials have to be shipped from Russia or this one causes more pollution in the extraction of this material to build it. So, when I have material choices, [I need to] consider those things. I think it is important and I would like our widget engineers to think a little tiny bit more like that. (KSEE2)

One of the panel members (KSEE1) suggested creating an overarching theme or an overarching category, probably titled as ethical, environmental, and humanitarian considerations, which can encompass all other values including sustainability, desire to serve humanity, and safety. Considering all comments regarding sustainability and desire to serve humanity, sustainability was considered as an ethical and moral value as it is related to safety or do no harm; however, desire to serve humanity or humanitarian considerations was regarded as a contextual value that can vary dependent on the specific context, scope, and intentions of engineers or values of engineering firms.

As for the *Being Methodical* theme, one participant commented as "I am okay with it not being methodical because I do not want and miss out on all of the other aspects of what they should be doing to accomplish a goal" (KSEE3).

At the end of the focus group meeting, the panel members were asked to rate each epistemic aspect of engineering that emerged from the Delphi study. Table 4.8 indicates the mean and model values and the standard deviation for each epistemic aspect. It appeared that the panel members of the focus group considered all five of the engineering design stages very important for K-12 science and engineering. Besides, several key epistemic aspects of engineering including *Modeling*, *Multiple Solutions*, *Empirical* and *Trade-off Making Decisions*.

The panel members of the focus group were also asked to rate the importance of *Empirical Norms, Communication Norms,* and *Failure Laden* that were given a separate category at the end of the Delphi study based on the comments. It seemed that the panel members considered *Empirical Norms* and *Learning from Failures* were important, but *Communication Norms* was regarded as relatively less important.

Table 4.8

Descriptive statistics for each epistemic rated in the focus group meeting

Epistemic Aspects		Mean	Mode	*SD*	Rank Order
Knowledge Base for Engineering	Scientific knowledge	4.71	5	.49	3^{ab}
	Mathematic knowledge	4.71	5	.49	3^{ab}
	Technological knowledge	4.71	5	.49	3^{ab}
	Engineering knowledge	4.86	5	.38	2^{b}
The Stages of Engineering Design	Problem definition	5.0	5	.0	1^{b}
	Identification of design specifications	5.0	5	.0	1^{b}
	Idea generation	5.0	5	.0	1^{b}
	Idea evaluation	5.0	5	.0	1^{b}
	Design refinement	5.0	5	.0	1^{b}
Key Aspects of Engineering Design	Communication	4.71	5	.49	3^{ab}
	Collaboration	4.71	5	.49	3^{ab}
	Modeling	5.0	5	.0	1^{b}
	Multiple solutions	5.0	5	.0	1^{b}
	Empirical	5.0	5	.0	1^{b}
	Failure-laden	4.43	5	.79	6^{a}
	Iterative-reflective	4.57	5	.79	5^{b}
	Creative	4.71	5	.49	3^{ab}
	Trade-off decision making	5.0	5	.0	1^{b}

	Socially-embedded	4.86	5	.38	2[b]
Values and Norms of the Engineering Community	Do not harm (Safety)	4.14	4	.69	9
	Integrity	4.71	5	.49	3[ab]
	Honoring intellectual property	4.43	5	.98	7[a]
	Functionality	4.29	5	.95	8
	Learning from Failure	4.57	5	.79	5[b]
	Empirical norms	4.71	5	.76	4[ab]
	Communication norms	4.0	3	1.0	10

Note: Epistemic aspects rated based on a 5-point Likert scale (1= Strongly Disagree... 5=Strongly Agree).

[a] Aspects with the same mean ratings were ordered starting with the smallest standard deviation.

[b] Aspects with the same mean ratings and standard deviation were assigned with the same ranking number

Overarching Themes

In this section, the overarching themes that are not necessarily linked to the categories of the epistemic aspects of engineering including the knowledge base, the stages of the design process, key aspects of engineering, and the values of the engineering community but rather connected across the categories, were presented. Put it differently, larger analytical categories or more abstract themes/concepts were generated based on links among the themes that emerged from the Delphi study. The relationships between themes by which the overarching themes were developed were often implicitly or explicitly addressed by the panel members. This process, as Charmaz (2006) underlined, represents the co-construction of knowledge by the researcher and the panel members. A visual map was presented (see Figure 4. 1), indicating the themes and their relationships. The relationships and the overarching themes were further explained and supported with the accounts of the panel members of both the Delphi study and focus group.

Theme 1# The Knowledge Base of Engineering is not the Mere Application of Science

Engineers benefit from scientific knowledge as “modern technologies that engineers work on frequently operating on the bases of physical laws and properties of matter that require a relatively sophisticated level of scientific understanding” (EEP1). However, engineering, contrary to the common assumption, is not the mere application of knowledge drawn from natural sciences. Instead of borrowing that knowledge from the science discipline, they transform that knowledge for practical uses in the design process. This is not an inferential process but rather a reconstructive process demanding the reconstruction of the necessary knowledge to integrate it into the design process and eventually to design artifacts. Engineers examine the knowledge from an “engineering lens”, or in other words, they are “differentiating” and “integrating [it]… from an engineering standpoint” (EE11) or “[engineers] see it (science knowledge) in an engineering context. That it is not enough that they have the fundamentals” (EE11). Even some panel members differentiated the knowledge being transformed from pure scientific knowledge: “*engineering science knowledge* which is somewhat different than physical science and natural science knowledge because it was developed primarily for use by engineers, primarily for use to design artifacts” (EEP4) Others claimed that scientific knowledge and the knowledge used in engineering, even if their names and roots are same, are presented in a different way as the following example provided by the panel member indicates: “thermodynamics is taught differently to engineers than it is taught to physicists, it is the same basic idea but the goal of it is different” (EEP4).

Theme 2# The Knowledge Base is Interdisciplinary and Multidisciplinary by Nature

Engineers call on knowledge from a wide array of disciplines throughout the design process as one panel member stressed that “Engineers use a diverse range of knowledge that spans various topics" (EE7). They use any knowledge that is relevant and useful for a particular problem as one of the panel members expressed: "Engineers essentially use whatever knowledge they have to do design. That means engineers use both, any scientific knowledge that works for them, any engineering science knowledge works for them, any empirical knowledge works for them" (EEP4). Additionally, the engineering knowledge base may also involve technological knowledge, or in other words, "working knowledge of existing technologies, parts, materials" (EEP1), and "existing design approaches and tools from the relevant engineering field" (PE1) as well as social knowledge, in other words, "understanding something about the social benefits, the social costs, the ethical implications, the environmental ramifications" (EEP1).

Several other panel members also emphasized the necessity of technological knowledge for achieving solutions as the following observation illustrates:

> Many people wrongly think that engineering is just the application of math and science to technology. To some extent, of course, engineers do apply math/science. But the whole reason engineers have specializations is because they need to understand certain technological systems in order to engage in meaningful design. (EEP6)

The following observation indicates how different forms of knowledge needed for the designing activity:

> Relevant scientific knowledge; if you are going to use the electricity you need to understand something about the electricity…In order to understand the science, mathematical skills are usually necessary. In addition, engineers need to understand the problem for which the solution is sought and relevant social aspects. A traffic problem would need a solution that incorporates the understanding of drivers' behavior, for example. An improved home oven would need an understanding of the cook's

> preferences. Engineers also need to understand safety and risk analysis. A solution is often sought in order to reduce risk and improve safety, but the solution often entails risk as well. An understanding of risk tradeoffs is necessary. Engineers need to understand economics as the design needs to meet economic requirements. Engineers need to understand the potential impact of their work on society (EEPE7)

On that account, one can easily conclude that the problems that engineers tackle are so complex and complicated that engineers require an interdisciplinary approach to generate solutions. Engineering is socially embedded which means that engineers are tasked with complex and complicated ever-changing societal problems.

Besides, they collaborate and communicate with individuals from a vast array of disciplines to bring to bear the knowledge to work on engineering problems. In the problem definition phase, engineers use any kind of knowledge that is useful to design their engineering artifacts. One panel member, for example, underlined this point as: “They first need to understand the problem itself. From there one needs to identify what basic principles should possibly be applied to the problem” (EE3).

Hence, the integration of the knowledge drawing from different disciplines is performed not only through analysis but by synthesizing that knowledge for practical purposes. Thus, engineers need to synthesize and apply that knowledge to a particular problem as two panel members emphasized. One panel member, for example, asserted: “On Bloom's taxonomy, the design is at the apex - synthesis - bringing together knowledge from other disciplines, evaluating it to perform analyses, and create a new solution. Synthesis is an important capability for life-long learning, creativity, and making progress” (EEPE4).

It is worthwhile to mention that the knowledge exploited from different disciplines is integrated into each phase of the engineering design process which indicates that engineering problems are defined, and solution ideas are evaluated from “scientific, safety, economic, and social perspectives” (EE8).

Theme# 3 Practical Knowledge is Important for Design Activities

Practical knowledge composed of experiential knowledge and/or theoretical knowledge. In the case of engineering, how to execute the engineering design process, how to apply relevant knowledge, how to integrate scientific, mathematical, technological, or social knowledge into the design process in order to design practical solutions can be considered as practical knowledge. One panel member of the Delphi study illustrated this point as follows: “Engineers need a wealth of knowledge, but the necessity of being able to utilize that knowledge (factual information) when needed and when appropriate” (EEPE6). Along with same line thinking, another panel member explained what makes engineering different from the other discipline as the commands of knowledge: “engineers must have expertise in science and math. This seems obvious, but a command of science and math and other technical knowledge is what makes an engineer special and able to do things that non-engineers are unable to do” (EEP5). One of the panel members endorsed this view by putting emphasis on the importance of how knowledge is applied in the design rather than the knowledge that engineers should have as follows:

> In my opinion, the nature of the knowledge that engineers use when designing engineering solutions is the knowledge of the process itself. Being an engineer and designing engineering solutions is not about what engineers know. It is all about how engineers think. Many engineers share a similar knowledge base and yet are able to develop unique engineered solutions based on how that similar knowledge bases are

> applied. In this regard, the development of an effective engineering solution is less about the engineering knowledge applied and more about how that knowledge is applied. (EEP4)

The knowledge about how to perform the design process, for example, comprises how to model, how to prototype, how to make trade-off decision making, how to do optimization, etc. Engineering students learn those during their undergraduate programs; however, what differentiates an experienced engineer from a novice engineer is practical knowledge. One panel member, for instance, made the following point:

> You can get all the math skills and science skills in the university classroom but that does not mean that you are going to be a successful engineer. It is only building the experience, but it is through building the experience and using those skills that you become a successful anything. (EEPE2).

The practicality is essential to engineering practices as one panel states: “There is a profound sense of practicality in the community that can be considered a downside because of the inability to see the writing between the lines. I think there is an unspoken rule of always being practical” (EEP8). This point was further emphasized by indicating that engineers often make their decisions based on their experiential knowledge:

> Engineers typically go with whatever their best information is and sometimes the scientific theory sometimes it is just an empirical. It may not have any theory underlying it, but we know based on just experience that if we do this, this happens. We might not know why it happens, but we know it happens consistently so, just experience of how things typically work, and rules of thumb based on the observation that engineers use. (EEP1)

Two panel members emphasized the importance of experience for engineering judgments that they use for the decision-making processes. One panel member portrayed engineering judgment since the “we use test results, other heuristics, other rules of thumbs that allow us to make decisions when we do not have all the information” (EEP4). Another endorsed this view by asserting that “knowledge based on the experience of the individual - important as a check to initial designs, confirmation of compliance and safety, adjustment of designs” (EE11). Also, “engineering judgment comes from experience. Good judgment comes from experience and experience comes from bad judgment” (EEP4).

Therefore, based on experiences, engineers develop “intuitive understanding” as one panelist justified in the following statement:

> At the root of the engineer's knowledge in mathematics and science. Over time, with experience, the engineer can form an "intuitive" understanding of how a scientific principle/construct will interact in the performance of a designed solution, but in a complicated solution, the mathematical analysis to predict and model, and optimize a solution is uniquely characteristic of the engineer. This knowledge is important because it enables the engineer to optimize and not compromise the safety and effectiveness of a solution. (EE9)

Likewise, one panel member addressed the inherent way thinking gained through theoretical knowledge and experience as follows: “For many engineers, the design process has become their inherent way of thinking and a natural approach for problem-solving” (EEPE2).

Theme 4# The Knowledge Base of Engineering is Cumulative

Engineering knowledge base is continuously expanding as the knowledge built in performing the engineering design process. The knowledge gained through learning from failures and successes as one panel member, for instance, described: “Engineering knowledge advances by learning from failures (e.g., Tacoma Narrows). This is a form of variation and selection” (EEP4). The panel member elaborated on the notion that engineering knowledge evolves in a sense of variations and selection which means that engineering knowledge is developing based on the selection of what worked and what did not work. Also, several other panel members stressed that design failures inform future engineering activity and even contributes to the creation of inventions: “I know that is how a lot of inventions have come about is just from mistakes that were made” (EEPE8); “Success tells you very little, but failures show that you have exceeded the limits of the design” (EEP4).

The panel members also stressed the significance of the knowledge coming from the practice (EEP4, EE11, EEP6). For instance, consider the following statement:

> There is always a limit in what engineers do, they sometimes use heuristics, they use rules of thumb and they try out something. They basically do empirical sorts of studies, when they do not have any theoretical understanding of how airplane wings are supposed to work, then [they are] going to just have to try different stuff and see how they work under test circumstances, [in this way] they developed new knowledge. (EEP6)

Theme 5# Engineering Involves both Technical and Non-technical Elements

Engineering design involves both technical and social as well as creative practices that are intertwined with each other in the design process. As the panel members of the focus group underscored, in order to embrace all students’ potentials, it is important to introduce both technical and non-technical, social aspects of engineering.

Engineers are concerned with the technical requirements that their design artifacts fulfill. For example, one of the main values that the engineering community pays attention to is the functionality which is about whether their engineering artifacts function as intended. Engineers also appeal to the scientific principles, use mathematics and technology knowledge, define engineering problems, they model and prototype design options, test, and evaluate those problems and make trade-off decisions in the light of empirical data. All these practices necessitate technical knowledge and abilities for the successful design of a product or execution of an engineering project. On the other hand, seeing engineering as mere technical processes misses the inherent social processes which serve as a backbone of the design process. When taking the context in which those practices are enacted and how those practices are put into application into consideration, it appears that communication and collaboration are playing a crucial role in this process. Collaborative work is necessary even in the problem definition phase because engineers may need to deal with ill-structured problems as one panel member stated in the following observation:

> When presented with a problem, it is not necessarily stated in a way that helps the engineer identify specific problem needs and solution requirements. This can sometimes take collaboration. So, the engineer needs to know how to work with others, laypeople, and experts from other disciplines. (EE9).

Collaborative work plays a crucial role in the whole design process since there are various roles and activities that engineers need to carry out. Consider the following statement:

> While being a part of a team, you are putting together a network infrastructure you typically do not do that by yourself. There are various roles and there are various job casts that align with those roles, not to mention the other aspect of learning. (EEP3)

Thus, engineering designs are outcomes of collective works which are carried out by not only a group of engineers but also experts from a wide range of disciplines as one participant exemplified, engineering work involves "finance people, sale people executives, purchasing people, etc." (EE2).

As an inherent part of collaborative works in engineering, communication, "whether it would be spoken, written, or visual,…[is also] hugely important to engineers" (EEP4) on the grounds that engineers have to interact with multiple people as one participant voiced in the following observation:

> Engineering projects often cut across not only multiple individuals, but multiple teams, multiple divisions of a company, or even multiple companies involving contractors, subcontractors, and vendors. On that account, communication, coordination, and logistics within and between organizations are often crucial to the success of engineering projects. (EEP1)

Thus, one who pursues a career in the engineering discipline should know that "they spend their time 70% of it (engineering activity) with communicating whether that is between two engineers, higher-ups, clients, whomever" (EE5). The reason for this is that "[engineering] work does not have a very large chance of succeeding and the current problems that we face as a society are just so complex that we do really need multiple perspectives to make it happen" (EE5). In addition, the panel members of the focus group justified that reflection practices necessitate a substantial amount of communication since engineers need to have a critical examination of each phase of the design process to make an informed decision concerning the next steps as well as the whole design process to learn from their experience.

Besides that, engineering work is socially-embedded which means that engineers need to collaborate and interact with end-users to be able to understand end-users' needs and problems as "the end-users are the ones that will be using the design and it is important that the design solution addresses these needs" (EE6) and that interaction requires communication as one panel member highlighted: "if they cannot explain and sell their idea, then it is not going to help anyone" (EEP5). Also, given that engineers produce solutions to societal problems such as "global warming", it is important to understand the societal trends, needs, and desires if "engineers are tasked with developing for humanity… the only way to understand the experiences and desires of a person outside their daily life is to listen and work hard to understand their situation" as well as "gather information from them" (EEP3). However, communication is "also critical to designing inclusively. If engineers only designed for themselves, then they would only have to understand their own experiences and desires" (EEP5).

Additionally, engineering is a creative process in which creative insights are invaluable to produce innovative solutions to complex societal problems and solutions that provide society new power and convenience. Consider the following statements: "with the theoretical knowledge alone, engineers do not think of the artistic (creative) aspects of the design… that leads to innovative ideas" (EEP2); "I am seeing more large-scale societal problems that society tackle. The project is larger and turns into a broader impact and we need to be more innovative because we need it, so engineers should be more innovative" (EEP2).

Theme 6# Bounded Nature of the Engineering Solutions

Each engineering design solution is unique to the design context and the aim of engineers is not to produce a "perfect solution" or "most optimal solution" but rather a "sufficient" (EEPE4) or an "acceptable" (PE1, EE8, EEPE5) or "satisficing" (EEP6, EEP1) solution to a particular problem as one panel stated that there is no "affordable and gold".   In Round 3, one panel member, for instance, challenged the idea of "the most optimal solutions" as: "If there are "most optimal solutions", why are products ALWAYS steadily improved upon over time?" (EEP1).

The design process is about trading between qualities and variables in order to create a sufficient solution through trade-off decision making (EEPE4, EEP1). Put it differently, since engineers cannot have the optimum of each quality, they have to make trade-off decisions to design a "sufficient" or "satisficing" solution within a context with various design constraints. As one panel member claimed in Round 2, engineers attempt to find "a good enough solution to a given problem because of [design] constraints." Thereby, "typically, engineers will settle on the good enough solution, pass that along, and only seek another if the need arises" (EEP6). For this reason, the panel member suggested replacing multiple solutions with ill-structured solutions. The idea behind this revision was that given that engineering solutions are bounded with time and many other constraints, the design process yields ill-structured solutions rather than "perfect" or "the best" solutions.

Engineers can have multiple potentially viable solutions to a particular engineering problem but not the perfect solution as several panel members indicated: "There may be many acceptable designs to solve a problem, each with unique pros/cons" (EEP1). Engineering solutions emerge in the context of social interactions, communication, and conflict among engineers, stakeholders, and end-users. In that regard, engineering is bounded within a specific social context in which engineers seek out satisficing or sufficient solutions to a given problem. What counts as a sufficient solution, therefore, is constructed by engineers in a specific design context because of "constraints, and trade-offs, customer and designer preferences", (EEP1) or in other words, "the scope, context, and intention of the design" (EPP6) all affect the outcome."

Theme 7# Tentative Nature of the Design Process

First, consider the following statement for this theme: “The details of the stages of the engineering process will change with the product or solution being developed” (EEPE1). To be more specific, most elements of the engineering design process such as problem definition, design criteria, engineering decisions as well as design approach can be modified and revised throughout the engineering design process considering the following factors stated by one of the panel members:

> Design requirements are often subject to interpretation; the expertise and knowledge needed to solve a design problem may not always be known in advance because they may depend on the nature of the proposed solution; constraints and requirements may change during the course of a project. (EEP1)

Additionally, engineering problems tend to become tentative throughout the design process since possibilities and issues can arise during the design process such as design failures, and thus there may be even a need to reframe problem definitions. In that respect, one panel member suggested in Round 2:

> I would add the engineers need to communicate the problem as well. The problem statement may change over time and they may get a clearer picture of what it is they are really trying to do with their design. So, the process of restating and communicating the problem with the team is just as important. (EE7)

From this perspective, one panel member underlined the importance of “remaining open to altering and/or adding to the established problem over time” (EEPE6). Also, as another participant pointed up, design specifications are revisited as the design proceeds inasmuch as “the boundaries of the design problem often take shape as the engineer works on the task, and specifications/criteria are often re-negotiated between the stakeholders at multiple points in time" (EEP6). For this reason, engineers need to "update [their] understanding of requirements, constraints, evaluation methodology, or plausibility of a chosen solution" throughout the design process" (PE1).

The non-linear and iterative nature of the engineering design is often associated with the refinement phase in which iterations are employed in order to improve the end-product. However, changes not only take place when refining the product but when modifying other elements of the design process such as problem definitions and design criteria. This is because these elements are also subject to change during the design process in light of new information and new data that arise as well as when encountering obstacles or design failures at any point during the design process. Design failures are sometimes associated with the design problem. For instance, "sometimes this (the design process) may be interrupted by realizing that you are designing for the wrong problem" (EE5). The new information can be obtained from the initial analyses of solution ideas in the idea evaluation phase as one panel member claimed: "the process is not always so neatly linear. Sometimes it is best to move back based on difficulty in prototyping, or unacceptable results in the evaluation" (EE4). The new data may come from the renegotiations of the design criteria with clients and stakeholders. Hence, the non-linear nature of the design process is not only related to the need for improvement of engineering designs but also related to the need for revising engineering problems and design specifications or minimizing design failures. Therefore, revisions do not necessarily start in the design refinement phase but rather the revisions and modifications may be needed as early as after engineering problems are formulated.

Theme 8# Engineering Design is a Reflective Process

During the design process, engineers reflect upon their design experiences in order to obtain feedback and eventually, learn from them. In the following statement, a panel member, even though implicitly, addressed the importance of reflection in engineering:

> Engineers need to be able to draw on their life experiences, examine them critically, and be willing and competent enough to dig into these experiences to understand them. This is one of the biggest needs in order to see and define problems. (EEP5)

The same panel member of the Delphi study suggested that reflection serves as a driving force of design iterations as follows: "the reflection is what moves the engineer from one iteration to the next--whether it be in a brainstorming stage or a prototyping stage". That's why engineers need "to think over what they have done and determine what they need to do next for a very intentional reason". The decision was first to associate reflections with the only iteration process. However, engineers begin to reflect on what they do and what they involve after they formulate their design problems. As the tentative nature of engineering design elements suggests, engineers need to verify their problem definitions as they proceed and evaluate whether solution ideas, conceptual designs, models, and prototypes meet the design specifications. Besides, engineers reflect on failures that they encounter during the design process and empirical data to decide how to proceed in light of this new information as another panel member of the Delphi study suggested: "empirical and failure laden can be wrapped into iterative and reflective. What information are you reflecting on if not empirical evidence and failure?" (EEPE4). Reflections on each element of the design process, in this case, become a necessity as one panel member stated as in the following statement: "having reflection play a role in each piece of the design is crucial" (EEP5).

One Delphi panel member suggested in Round 2 the inclusion of reflection at the end of the engineering design process in order to learn from their own experiences as follows: “the reflection also occurs after the project is completed. The reflection is done to examine what you did in order to possibly learn from it” (EEP4).

To make reflections, communicating the design process and solution is vital as one panel member argued indirectly on this issue as follows: “The engineering must be able to communicate technically analysis, the solution, its requirements, and specifications, how it was optimized, and how it should be tested, implemented, and monitored” (EE9).

Likewise, one panel member (KSEE3) in the focus group, suggested making the connection between reflection and communication in the following justification: “Reflection is a lot of times connected to the communication ability of students… but it (making reflections) still depends upon the vocabulary that they have and how they build an argument,… if you are trying to unpack their experiences”.

Besides, one of the panel members in the focus group advocated the integration of reflection practices not only in each phase of the engineering design process as well as before and after the design process. Consider the following justification:

> We need to take time to talk about what people come up with different ideas to address the same problems or same issues and they created multiple solutions for the same idea, how they were created during the process and to what extent they used the empirical data to test their design ideas and what they did during design; if they had a failure, how they were able to fix or overcome those kinds of failures. (KSEE5)

Theme 9# Engineering is not only a Process of Problem-solving but also a Process of Decision-making

As aligned with the common assumption, it was stated by several panel members that "the basis of what we do all the time is problem-solving" (EE3). In the design process engineers are required to obtain enough information regarding the problem and the necessary tools to solve the problem. Although other panel members did not explicitly point out the centrality of the problem-solving process in the design process, it was evident in their descriptions of the stages of the engineering design process which always starts with a problem that needs to be solved. On the other hand, a close examination of the practices that engineers engage in unraveled the decisional nature of engineering design. To be more specific, engineers need to make a wide range of decisions throughout the design process in order to ensure a "successful" solution. They are making decisions on which option(s) fulfill the design requirements. As engineers cannot have the optimum of each quality, they need to make trade-off decisions to achieve a "sufficient solution" in given design constraints. They have to make ethical, moral, and legal decisions as several participants underlined: "To solve problems as effectively and efficiently as possible given the specific context. This requires ethical decision-making and care for anything affected by an engineering design including humans, animals, plants, air quality, etc." (EE8). They need to make those decisions as "it may have ramifications down the line for humanity" (EEP1). They need to know science and math principles and obtain sufficient data in order to make the best decision concerning design solutions as it was contended by the panel members. One panel member stated that "use the principles of science and the predictive capabilities of mathematics in order to base decisions on data" (EEPE4). Another panel member supported this observation by stating that "[engineers] take everything that [they] have learned and that [they] have to be able to make the best decision" (EEPE8). Consequently, the decisions made during the design process have a significant impact on the end-product.

It is also important to note that engineers make their decisions, often using empirical evidence (EEPE1) but also using their experiences (rules of thumb) (EEP1), or using engineering standards and rules (EEP1, EE11).

Theme 10# Engineering Design is an Open-ended Process

Engineering designs "cannot stop at the "select and refine a solution" phase" (EE4). Engineers constantly engage in a continuous process of improvement of their design when needs arise, thereby implying "design is never finished; it can always be improved upon" (EEP1). Also, consider the following statement supporting this idea:

> Engineers involved in continued support for products and so, if you keep building something for multiple years and one of the suppliers suddenly does not make a certain part anymore you have to go ahead and like maintain that so there is the life cycle aspect of it of engineer design like sales and procurement and until like getting the parts that you need for various designs is definitely part of the process. (EE4)

Two panel members considered the iterative nature of engineering as an important element to meet ever-changing design needs. Considered the following statements: "The iterative nature is typically driven by testing the effectiveness of individual aspects of the design. Because of the iterative nature, it is reasonable to say that the design process is ongoing and never really complete" (EEPE2); "The iterative nature of the design process, [part of the design process], means that you are going to evaluate the solution and determine if the solution is still valid" (EEP2).

In addition, engineering designs are socially embedded which means that engineering creates solutions to societal problems and needs. Also, given that the actual impacts of designs on the environment and society have been continuing to be revealed, engineers need to modify their designs to prevent the potential impacts of their designs on society and the environment. For instance, after becoming aware of the adverse effects of some materials that will not decompose or are non-recyclable, the value of sustainability has become ingrained in engineering. In response to these dynamic and evolving societal and environmental problems and needs, engineers take advantage of the opportunity of the iterative problem-solving method that provides to maintain the changing needs and problems. One panel member explained this point clearly as the following statement demonstrates:

> Over time, things change as society is not static rather it is very dynamic. Therefore, the solution that was developed at one point in time may not be applicable at a later point in time. Because of the iterative nature of the design process, it [the design process] can be readily applied. (EEP2)

Theme 11# Engineering Designs are Value-laden

It was evident in the participants' accounts that the values are embedded in engineering designs since engineering decisions made throughout the design process are based on value judgments. One panel member, for example, stated:

> I make those [engineering] design decisions based on whatever values I have in my head, in my heart, both personal values and values that have been instilled in me through my professional socialization and so, those values get embedded into technologies that engineers develop. (EEP1)

For instance, when designing programs for vehicles, engineers need to take into consideration various values as one panel member stated in the following example:

> [engineers decide on] how [they] program them to avoid accidents, how [they] program them to optimize the results of an accident and there are all sorts of the values, what is it [they] are valuing when you program out how a vehicle responds to a crash situation, do you want to protect the occupants of the car, do you want to protect things outside of the vehicle or what are you prioritizing. (EEP1)

Consequently, engineers need to decide what values they design their artifact around at the beginning of the design process. Ethical and moral values are paramount to the engineering design as every engineering artifact has certain risks that may influence society and environment in adverse ways. Consider the following statement:

> We want to design all our systems to be as safe as possible in the sense of not harming the user or harming society. We hope that they will harm the user very little or maybe not at all for many years, but eventually, no matter what you do, you will get some failures. So, you cannot have zero risks. There is always some risk. (EEP4)

For this reason, engineers try to minimize that risk by taking ethical and moral values into consideration throughout the design process.

Another main concern of engineering is to create technologies and systems that function and in turn, fulfill its practical use. This value was viewed as a substantial value of the engineering community by several panel members as shown in the following one of the panel members' claim: "Engineering designs should function as it needs to fulfill its purpose. If they do not do what they were intended to do, they have failed" (EEP1). To achieve that, engineers work toward fulfilling technical design requirements. Other values that the engineering community has can vary depending on the various social contexts.

One of the reasons why there may be multiple solutions to a particular design problem is because engineering designs are not "single-valued" as "different people will come up with different solutions which sometimes can be radically different but equally as effective, and there is no rote method which will lead to a preordained answer" (EEP1).

Theme 12# Contextual Values in Engineering

When collating all comments on the values in the Delphi study and focus group, the desire to serve humanity and other values were not considered as pervasive values in all engineering communities. It was inferred that the values including aesthetics, the desire to serve humanity, easy to repair, etc., are considered as context-dependent values. Different values may come into play (EE11) and become important in engineering design depending on the values and desires of the clients, organizations, and/or stakeholders as well as engineers' own personal values can become important. Although the ethical and functionality values are embraced as the core values of the engineering community, other values are specific to design contexts. In short, one can say that engineering discipline can be considered as a profession driven by core, ethical, and contextual values.

One panel member exemplifies how engineering values are context-dependent as follows:

> I believe that this (norms and values in engineering) varies depending on the problem being addressed. For example, if I am designing a brake system for a car, I would want one that is safe, cost-effective, reliable, and easy to repair. If I am rebuilding a road, I am looking at safety and meeting the needs of the community. While cost could be an issue, it is lower on the list than for a new car system. (EE3)

The values including serving clients and/or organizations were evident in explanations of the panel members. Thus, the values at play during the engineering decision making process change depending on the values of clients and organizations. One participant, for instance, described “ensuring the design addresses the end-users’ needs” (EE6) as a norm of the engineering community. Another participant also noted that clients’ values become more important than the values of engineers or companies as follows:

> We as the engineer or as the design firm never considered that becomes important because the client wants that piece to be and as long as it is not compromising that safety aspect of it and that ethical aspect of it. (EE11)

Another expert participant pointed out to the effects of organizations’ values in the engineering design process: “Engineers generally work within larger organizations and are expected to serve that organization. They are generally not encouraged to question the overall motives or trajectories of that organization” (EEP6).

As regards the value of sustainability, there was some controversy with respect to whether sustainability is relevant to all engineering professions among the panel members of the Delphi study. On the one hand, several participants regarded sustainability as an ethical value, specifically they included it under the value of safety or “do no harm”. For instance, one panel member of the Delphi study suggested that ethical values of the engineering community involve “implement[ing] ideas that solve the problem but safeguard the environment, the community that is affected by this (fauna, flora, and humans)…., long-lasting solution” (PE3). Another participant also expressed her concerns about the environmental impact of technologies as follows: “environment is something that comes up a lot with what we have done post-industrial revolution, great technological advancement not great for our environment,… we need to deal with the environmental concerns" (EE5). On the other hand, several other panel members advocated that sustainability could be taken into account in light of end-users' needs and desires. One panel member, for instance, advocated this position as follows:

> The values of our clients… For instance, if we have a client that values sustainability, that may rise higher up and our design might reflect that piece, …, so whatever it is I think it depends on whom we work for (EE11).

After the first round of the Delphi study in which sustainability was included as a value of the engineering community, it was rated relatively low as compared to the other themes and qualitative data including participants' comments also indicated that the value of sustainability is not applicable to the whole discipline as the following statement indicates: "Certain companies might be interested in sustainability, and engineers working for those companies would have to attend to those values. But I would say that it is demonstrably untrue that sustainability is a pervasive value in the engineering profession" (EEP6) On the other hand, K-12 science and engineering educators attending the focus group recommended the inclusion of sustainability under the ethical values of the engineering community. Consequently, in light of the comments, I decided to reinclude the theme as part of the ethical, environmental, and humanitarian considerations for the engineering community in order to inspire students and give emphasis on the care dimension of the engineering, even though it is not a pervasive consideration in the engineering community.

There again was a controversy between the panel members of the Delphi study as to whether the value of desire to serve humanity is a prevalent value for the engineering community. Some participants advocated "human-centered design" (EE5) which aims to "serv[e] society by solving problems of importance to elements within society" (EEPE5) as the following statements indicate “We construct for society in order to improve in order to make things better easier, faster, safer. I think that you always have to be cognizant of what society is to have better engineering” (EE11). However, it seems that this view may vary across engineering disciplines. Consider the following statement: “They have rules, for civil engineers, the first rule is everything you do is for serving humanity, serving society and people, that means something needs to be done by law” (EE3). Similarly, one genetic engineer stated that “I was trained in genetic engineering and that is a field where this (desire to serve humanity) is extremely relevant” (EE5). Furthermore, this lack of agreement related to their idealistic view of engineering or their own ideals of the discipline. Put it differently, several panel members mentioned that they wish the desire to serve humanity to become the core value in engineering as the following example shows: “Human-centered design is what I would hope is a core value in engineering, as engineering is about designing for people” (EE5). On the other hand, after the second round, some participants were expressed concerned that the desire to serve humanity does not reflect the values of all engineers or engineering firms. For instance, one panel member stated: “It is certainly an aspirational value of the profession at large, as given in the vision statements of engineering professional organizations... Yet, most engineering is done by private companies seeking profits by creating products and technologies that people want” (EEP1). One of the panel members further advocated this position as follows:

> I severely question whether that value is a meaningful one in the day-to-day work of engineering. Everyone would like to believe that they are serving humanity. Engineers typically serve their employers, like most professionals. I strongly reject this aggrandizement of the engineering profession. (EEP6)

On this issue, another participant pointed to different types of engineers or firms. Consider the following observation:

> I see a lot of engineers having concern for global problems,…, tackle those problems. [at the university], we have humanitarian engineering minors, there are companies or organizations like Engineers Without Borders who are going to work on problems for emerging problems; …but there are engineers who are very technical and do very little. (EEP5)

Three participants, for example, underlined designing creative innovations and providing people with new convenience or power could be other values that engineers embrace. Consider the following statement of one of the panel members:

> When Elon Musk put a Tesla in space, it was not serving humanity but the other things that Musk has developed with his company are engineering designs and I think that these creative inventions are also an aspect of engineering. (EE7)

Likewise, another participant stated engineers can design "for creation sake" or for design sake without addressing a specific issue or problem" (EE5). Along with the same line of thinking, the panel members of the focus group suggested framing some values in a way that the values include both humanitarian aspects of engineering such as betterment of society and other values such as designing innovative technologies that could change the world as "many students of other types do not want to interact with humans, who are very entrenched by numbers or designs and many of those end up in engineering" (KSEE1). Hence, in order not to exclude students who are more interested in the technical side of engineering, the values related to desire to serve humanity were not regarded as the core and pervasive values of the engineering community but rather considered as a contextual value that varies from context to context. That is to say, the values of clients and companies for which engineers work as well as engineers' own personal values can become the key factors in determining what values are incorporated in the design process.

Moreover, it has to be noted that even though ethical and moral values were regarded as the core values of the engineering discipline, they vary across social context and political system, etc. In this respect, one panel member justified the context-dependent nature of ethical values as follows:

> It is also important to remember that ethics and morals are fluid and are not written in stone. It is important to ask the question of where the morals and ethics are coming from; which country, which religion, which laws, etc. Once you know the source of the ethical line of thinking, you can be more confident in your following of those ethics and morals. (EEP8)

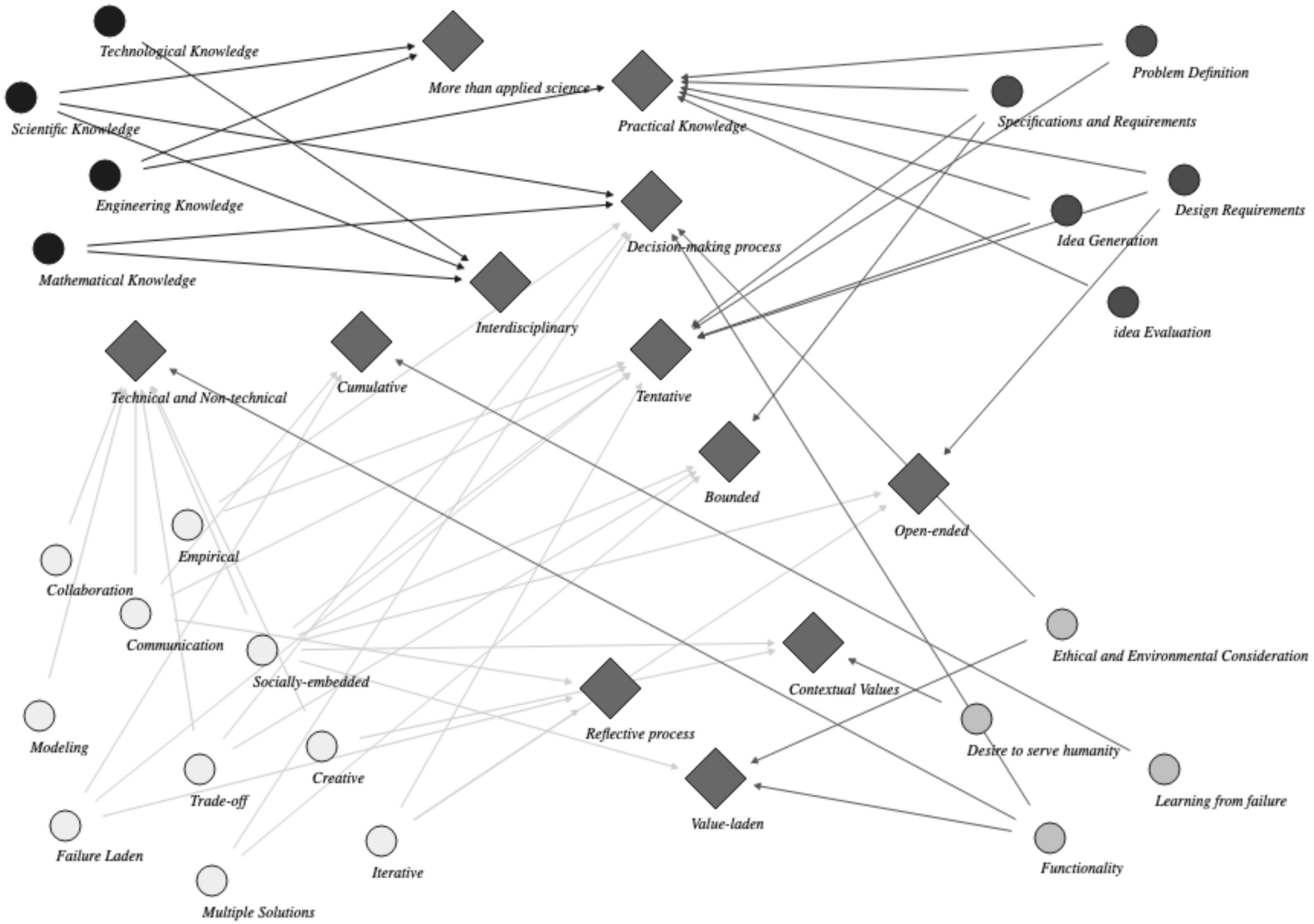

Figure 4.1 The relationships between themes and overarching themes

Notes: The diamond-shaped nodes represent the overarching themes and round-shaped nodes indicate themes that were derived from the Delphi study. The arrows represent the relationships between themes and overarching themes

Chapter 5

Discussions and Implications

This chapter comprised the following five main sections. In the first section, the findings of the current study were discussed, taking the account of the literature on the philosophy and history of engineering as well as college-level engineering education research in order to examine to what extent the findings were accord with the arguments of philosophers, historians of engineering and engineering educators. In the second section, the discussion of the findings was presented in the light of the existing literature on K-12 science and engineering education in order to highlight the contributions of this study to the pre-college engineering education. In the third section, the potential theoretical and pedagogical implications for K-12 science and engineering education as well as educational policy and teacher education were discussed. Lastly, the recommendations for the future studies and limitations of the study were provided in the last sections.

Overview of the Study

The overarching aim of this study was to shed light on the epistemic aspects of engineering to be integrated into K-12 science and engineering education. The Delphi method was employed to unearth expert opinions on the epistemic aspects of engineering. The expert panel member included engineering educators in higher education, engineering education researchers, researchers in the field of philosophy and/or history of engineering and/or technology and practicing engineers in the industry. Further, the focus group meeting was conducted to evaluate the results of the Delphi study from a K-12 education perspective. To be more specific, the discussion on which epistemic aspects of engineering should be an integral part of K-12 science and engineering education, how to tailor the findings to fit K-12 education as well as the grade levels. The qualitative data, consisting of open-ended responses of the expert panel members and their comments on the proposed themes and their description statements, were examined through constructivist grounded theory methodology (Charmaz, 2006) which enabled the researcher to develop overarching concepts for the epistemic aspects of engineering. Each epistemic aspect bears a relation to the other epistemic aspects of engineering, resulting in several theoretical or overarching concepts. Therefore, after the completion of the Delphi study and the focus group meeting, overarching themes were developed. The following discussions were structured around those overarching themes under which the themes emerged from the Delphi study were also addressed.

Discussions on the Findings of the Study in Light of Philosophy and History of Engineering Literature

The traditional view of engineering and technology posits that engineers seek out the practical use of scientific knowledge. That's why engineers borrow scientific knowledge in a straightforward sense to design the world (Kerr, 2016). Many scholars have challenged this view of engineering and many ethnographic and empirical studies have indicated that engineering is much more than applied science (e.g., Bucciarelli, 1994; Kerr, 2016; Radder, 2009; Shephard, 2006; Vincenti, 1990). Consistent with these studies, the current study pointed out four different forms of knowledge that engineers use and integrate to produce practical ends including scientific knowledge, mathematics knowledge, technological knowledge, and engineering knowledge. The panel members of the Delphi study indicated that even though scientific and mathematical knowledge are two important sources for the engineering knowledge base, it is not straightforward applications of these two forms of knowledge to design problems. Rather, the current study illustrated that engineers not only analyze but they synthesize that knowledge, look at it from an engineering lens to be able to integrate knowledge into the design process as well. This process needs more of the reconstruction process to tailor that knowledge to propose practical engineering solutions. Scholars from the fields of philosophy of engineering/technology and engineering education concurred that engineers, contrary to common assumption, need to transform the knowledge from natural science to produce practical solutions (e.g., Sheppard et al., 2006; Petroski, 2011; Vincenti, 1990). Sheppard et al. (2006), for instance, claimed that the use of science in the engineering design is not deductive but rather a creative and constructive process as engineering is not just a problem-solving process but it is also thoughtful integration of knowledge into the process. Even Vincenti (1990) argued that the knowledge that engineers use is different from scientific knowledge in terms of specifics. Vincenti further explained that the use of science and math knowledge in the engineering discipline requires a transformation due to the gap between the descriptions of natural phenomena in science and engineering design artifacts. Likewise, one panel member provided in the Delphi study the example of thermodynamics to point out that engineering students are introduced to science concepts in a different way than physics students. Another panel member even referred to this transformed knowledge as “engineering science knowledge”.

Further, the current study underlined that knowledge that engineers exploit is multidisciplinary and interdisciplinary in nature. On the one hand, engineering design problems require knowledge from a wide array of disciplines which is to say that engineers seek out input from other experts to bring to bear the knowledge necessary to approach complex and complicated engineering problems. On the other hand, engineers integrate knowledge from multiple disciplines in order to produce practical ends. In that regard, philosophers of engineering discussed that engineering knowledge is being transformed into a more hybrid form of knowledge (e.g., Sørensen, 2009). It was evident in the panel members' accounts that science and mathematics are not the only sources of the knowledge for the engineering community. The panel members argued that technological and social knowledge is also required to deal with complex and complicated societal problems and needs. A good understanding of how existing complex technological systems work, working knowledge of parts, tools, materials as well as previous solutions and failures working tools work enables engineers to determine appropriate ways in which they can engage in a meaningful design to generate effective solutions. By the same token, Vincenti (1990) stressed the necessity of the knowledge about the operational principles of technological devices for engineering. The operational principle describes how a device, or a technological tool works and behaves.

It was also suggested that social knowledge includes social benefits, human behaviors, and social costs as engineering designs are created to be used by people. Even when the aim of the design process is to generate innovative ideas that provide people new power or convenience, the understanding of human behaviors is necessary for "successful" designs. Also, given that engineering designs have a direct influence on society and the environment, engineers need to have an understanding of the ethical implications and environmental ramifications. Along with the same line of thinking, Latour (1987) highlighted that for successful innovations and inventions, knowledge about human needs and social context is crucial. During the Delphi study, even though the panel members recognize technological knowledge as a separate form of knowledge not necessarily specific to the engineering knowledge; however, they did not recognize social knowledge as an independent source of knowledge from social sciences for the engineering discipline but instead, they advocated that knowledge that engineers use in the design process be subsumed under engineering knowledge. In that regard, several scholars from the philosophy of engineering argued that knowledge from social sciences are not yet received enough appreciation in the engineering discipline and engineers approach problems from very simplistic presuppositions about human behavior; however, it becomes a necessity for engineers to benefit from knowledge about the social word to deal with today's complicated human problems and needs (e.g., Anderson et al., 2010; Sørensen, 2009). The Accreditation Board for Engineering & Technology [ABET] (2018) call engineering students to approach engineering problems from a broader perspective and understanding of global, social, cultural, economic as well as ethical factors. In that sense, knowledge from social science could contribute to the ethical and social aspects of engineering.

The current study also highlighted a distinct form of knowledge that pertains to the engineering discipline based on the panel members' accounts. It was pointed out a specific body of knowledge needed for employing engineering methods properly. This form of knowledge which was entitled by the researcher as engineering knowledge involves the knowledge about the design methodologies, knowledge about existing solutions, past successes and failures, together with existing ways and approaches to solve problems. Further, it consists of knowledge about how and when to use necessary knowledge, how to make trade-offs, how to optimize, knowledge of how to do modeling, prototyping, etc. This is what is necessary for meaningful design activities. This is similar to the knowledge that philosophers of engineering characterized as knowing-how and know-when (e.g., Dias, 2014; Dym & Little, 2000; Sheppard et al., 2006; Ryle, 1984) which is different from knowing-that. For example, you may well know how to play piano theoretically but you cannot play it properly until you gain a certain level of practical experience. The former knowledge is identified as declarative knowledge and the latter as procedural knowledge (Anderson, 1996; Willingham, 2009). Anderson (1996), who is a well-known cognitive psychologist, made a useful distinction between these two types of knowledge in order to underscore the importance of experience for practicality. Declarative knowledge mainly consists of facts and information and learning starts with developing declarative knowledge while procedural knowledge is the knowledge with respect to how to execute certain cognitive activities and this knowledge can be gained through applying declarative knowledge, in other words, practice. This point was addressed by the panel members such that they underlined the necessity of conceptual/theoretical knowledge but put more emphasis on experiential knowledge such as rules of thumb and engineering judgment as well as practicality for successful designs. Some panel members addressed the difference between the design process that novice and experienced engineers carry out. To be more specific, novice engineers follow the stages of the engineering design process usually and it looks in a sense more circular process, whereas experienced engineers focus more on what should be done, what is necessary at a particular moment and they perform them simultaneously rather than following the stages sequentially. This is aligned with the distinction made by the scholars in the field of engineering philosophy and history between knowing-that and knowing-how (e.g., Figueiredo, 2014; Jonassen et al., 2014; Sheppard et al., 2006; Picon, 2004). In line with what the panel members of this study underlined, Picon (2004) elucidated this point such that there should be an intermediate know-how between the knowledge obtained from courses, and judgments and decisions made by engineers. Likewise, Jonassen et al. (2014) highlighted that engineers often rely on their experiences or experiential knowledge to make engineering decisions. Therefore, besides declarative knowledge (knowing-that) involving knowledge about design procedure, engineering knowledge involves practical knowledge (also called procedural knowledge or knowing-how) which is crucial for the design process (Dias, 2014; Dym & Little, 2000, Vincenti; 1990). Dias (2014), for instance, called this type of knowledge as practice-based knowledge and supported the ideas that it derives from the design practice itself.

The current study suggested that the engineering knowledge base is not fixed but cumulative. As several panel members underlined that engineering knowledge advances by learning from failures as one of the panel members emphasized. As several other panel members underlined, learning from failure is crucial to the engineering discipline as failures could inform about the limits of the design and play a part in designing inventions. In a similar vein, Petroski (2018), who characterized design failure as a unifying principle of the engineering design process, claimed that failures if learned from are important sources for the knowledge base of engineering. Also, the current study demonstrated that communicating and reflecting, in other words, critically examining design experiences are essential practices through which engineers can learn from their own experiences. From this perspective, it was inferred that the themes of learning from failure and communication norms identified in the Delphi study could be considered to be two essential ways to contribute to engineering knowledge. Put it differently, documenting the process including effective and ineffective ways and approaches, together with the obstacles and failures that engineers encounter during the design process as well as successful design solutions not merely promotes the knowledge of individual engineers but also could contribute to the knowledge base of engineering in a general sense. In that regard, Johnson (2017), for instance, underlined that engineers have obligations to report the design failures, explaining how and why design failures occur. In a similar vein, Sheppard et al. (2006), which claimed that engineering knowledge is constantly changing and expanding, provided an explanation of how engineers contribute to the knowledge base. The scholars indicated that engineers are reflective and methodical and thus, they consider how physical systems function and how engineering activities are performed at the end of the design process which eventually develops their tacit and conceptual understandings. They can, later, use that knowledge for their future engineering works. Further, engineers share that knowledge with the community through publications or conference discussions. The knowledge that Sheppard et al. (2006) underlined here is generated from the engineering design activities which is similar to what this study described as practical knowledge.

The current study identified five main stages of the engineering design process which are, to a great extent, accord with previously proposed engineering design models for engineering students and novice engineers (e.g., Dieter & Schmidt, 2009; Earle, 1990; Voland, 2004). The problem definition was regarded as the backbone of the design process by the panel members on the grounds that in many aspects, this phase determines the direction of subsequent engineering activities and ill-defined problems do not often result in successful solutions. Even one panel member argued that many design failures can be traced backed to ill-defined or incomplete problem definitions. By the same token, several scholars also discussed that any change in the problem statement will lead to different ends (Dieter & Schmidt, 2009; Dym & Little, 2004; Earle, 1990; Voland, 2004). This is the phase where engineers gather as much information as possible with regard to the engineering problem. Before formulating design options, design requirements and specifications, design objectives, and what counts as a "successful" design should be established. The next is the idea generation phase in which engineers take multiple perspectives into consideration to generate multiple viable design options. This phase also involves developing conceptual designs, technical drawings, etc. Engineers, then, evaluate the idea solutions, using qualitative analysis to narrow down solution ideas to few which are later used for constructing prototypes and models. However, not all engineering designs involve creating physically working prototypes. The panel members of the Delphi study underlined the differences between prototypical and non-prototypical engineering systems. In prototypical systems, engineers engage in prototyping in order to test and evaluate their solutions and if necessary, refine them while in non-prototypical engineering systems such as structures, it is nearly impossible to create prototypes during the design process. In that sense, it was suggested that different types of evaluation methods such as inspections, checking details during the construction phase. Along with the same line of thinking, Bulleit (2014) highlighted the differences between these two types of systems such that prototypical systems can be tested and evaluated in a shorter time frame by reducing uncertainties that engineers are dealing with during the design process because engineers can integrate immediate feedback obtained by the testing and evaluation phase into their design. However, in non-prototypical systems, feedback is obtained and integrated into the design later. The feedback in the non-prototypical systems usually gathered after the design is built as a form of failure (Bulleit, 2014). Therefore, the evaluation and refinement of idea and design solutions differ in terms of the nature of engineering systems.

It is worthwhile to address that the panel members constantly cautioned that engineering design rarely follows a linear, step-by-step path but rather engineering design is a non-linear process in which many phases are performed simultaneously. The design models depicting the process into separate distinct stages, therefore, do not represent the accurate picture of the process that professional engineers engage in. On the other hand, they underlined that teaching the design process by breaking it down into the stages is beneficial for novices to introduce guidelines and rules that govern the design process. In that regard, Bunch and Pederson (2015) argued that engineers usually work under multiple uncertainties consisting of a lack of necessary knowledge and data which results in the need for several revisions.

Before proceeding to the next epistemic aspect of engineering, the theme of socially embedded was first discussed since it is related to and embedded in other aspects. Most panel members addressed that engineering design cannot be considered independent from its social context. First, engineers generate engineering solutions for clients/customers or companies that they work for, thus requiring constant interactions with them and integrating their needs and wants into the design process. In this sense, considering how end-users will interact and experience with the product is crucial for creating a successful engineering product. Also, engineers often work in large engineering firms and institutions. In this sense, they are expected to give priority to the values of organizations that they work for. Besides, engineering, as a part of society, is influenced by the societal, cultural, and political factors and in turn, the outcome of the engineering activity has an impact on society and the environment. Some even considered engineering to have a considerable amount of impact, more than generally assumed since they thought that engineers engineered the entire planet. As the panel members mentioned, several scholars also pointed out its transformational power (Lavelle, 2015). For instance, Layton (1991) considered engineering as “an instrument of social change and social revolution” (p. 74). The relationship between engineering and society was described as transactional by the panel members in that society brings things and engineers incorporate. Engineering is a manifestation of society and it is embedded in social and cultural contex. In a similar way, scholars discussed the inseparable link between society and engineering as engineers respond to ever-changing societal needs and problems (Ambler, 2015; Bunch & Pederson, 2015; Zwart & Kores, 2015). Customers’ or society’s needs and problems are not the only concerns that engineers have to deal with. Apart from the positive impacts that most engineering systems have, there are inevitable either intentional or unintentional negative impacts of engineered technologies and systems on society. In that regard, the panel members stressed that engineers should take the potential consequences of their designs into consideration.

The findings of the study underlined the importance of both technical and non-technical aspects of engineering. Technical practices are vital to properly carry out the design procedure. Several important practices were emphasized by the panel members including modeling, trade-off decision making, and iterative design. Engineers engage in a variety of models including mathematical, scientific, and engineering models in order to examine how a system works as well as predict the behavior of an engineering system that does not exist yet. Likewise, scholars emphasized that models, as a way to contact with reality, are valuable instruments to be used in many ways when generating solution ideas, optimizing solutions collecting data, and communicating solutions (Bulleit et al., 2015; Vincenti, 1990; Zwart et al., 2013). The panel members also underlined that modeling becomes more prominent especially when prototyping is difficult or economically unfeasible. Trade-off decision making was another integral component of the design process addressed by the Delphi panel. Since engineering solutions do not always have the optimum of each quality because based on the given design specifications and requirements, engineers need to make trade-offs between variables. van de Poel (2009) and Voland (2004) suggested that engineering judgments as to the trade-offs are an inherent feature of the engineering decision-making process and are required in order to resolve the conflict between design values. The iterative design process was also stressed by the panel members as one of the most significant features of the design process which enables engineers to improve or redesign their artifacts. It is rare, more than it is assumed, engineers achieve a practical end at their first attempt due to unexpected failures, or obstacles that they often encounter during the design process. They, thus, need to iterate the design procedure until the solution succeeds. On the other hand, several panel members considered the iterative process “a double-edged sword” for engineers because there is always an option to improve their design while this constant iteration could be never finished and due to time constraints, they have to complete their designs at some point. For this reason, it was stressed that engineers should clearly define what acceptable solution for their design at the beginning so that they can use iterations until the desired solution is achieved. Similarly, Dieter and Schmidt (2009) also pointed out this paradoxical nature of iterative design to inform engineering students regarding the nature of the design procedure. Also, scholars who developed engineering design models stressed that even though the models depict the design process as a circular diagram, the iterative process is often taken place throughout the engineering design (e.g., Dieter & Schmidt, 2009; Earle, 1990; van de Poel, 2009; Voland, 2004).

Failure-laden and empirically-based are two important aspects of the engineering design that were acknowledged by the panel member in this study. Specifically, the panel members described design failures as the “inherent feature” of the design process. It was emphasized that it is rare to succeed at the first attempt as design failures may take place before the desired outcome is achieved. It was also highlighted that it is important to be conscious of possible design failures in order for avoiding or preventing possible failures. In a similar vein, several scholars asserted that design failures in most engineering designs are inevitable. One of the reasons for this is that engineers often work with various uncertainties such as lack of knowledge and constantly changing design details (Bucciarelli, 1994; Madhavan, 2015). The empirical aspect of engineering was considered by the panel members especially critical in testing engineering designs in order to determine whether idea solutions fulfill the design requirements by quantifying design performance. That is to say, they can describe what a “successful” solution should be. On the other hand, one panel member suggested another important role of empirical data in the design process. Engineers mostly tend to rely on empirical data if there is no sufficient knowledge necessary to create solutions. In line with that Vincenti (1990) pointed out the importance of empirical data in the design process where engineers have to deal with uncertainties. In this sense, empirical data could reduce the uncertainties associated with the design and potential design failures.

Even though the aforementioned technical aspects were regarded as critical to the engineering designs, viewing the engineering design as a mere technical problem-solving process misses the true nature of this discipline and elements that are essential to the design process. The long-held traditional view of engineering advocates that engineers are mainly concerned with pure technical aspects of engineering, thereby underestimating the role of social and creative aspects of engineering. As mentioned earlier, the design activities take place within a social context. For this reason, ethical, social, economic, political, etc. constraints are embedded in each and every phase of the engineering design process. In every engineering activity, engineers have to take those constraints into account. Even though some engineering design models presented in the literature and engineering books put emphasis on the integration of those issues in specific phases such as problem definition and idea generation (Earle, 1990; Voland, 2004), the study suggested that those issues should not be disregarded and embedded in each phase of the design procedure. For example, trade-off decisions are made not merely for technical concerns such as functionality or efficiency but also for non-technical, social reasons as engineering work towards a wider social purpose rather than mere technical one (Schmidt, 2014).

Besides, it seemed that most of the panel members concurred that the social interactions play a crucial role in the engineering activities as they need to cooperate and communicate with multiple individuals, companies, and organizations to effectively execute engineering projects. The panel members put forward that in order for proposing effective solutions, experts from multiple disciplines and multiple divisions of a company are needed to bring their expertise to approach a problem from technical, social, economic, and political perspectives. In addition, several panel members suggested that engineers collaborate and communicate with not only with each other but also with end-users and stakeholders to fully understand the nature of engineering design problem that they address. Given that most engineers are tasked with serving humanity, they do not merely technically communicate each and every aspect of the design process, but they communicate with end-users to determine their expectations from the design product. The findings of this study are consistent with the previous work on the philosophy and history of engineering. A growing number of qualitative and ethnographic studies that investigated the engineering practices in natural settings illustrated that social processes are the backbones of the successful engineering designs process. In an ethnographic study, Bucciarelli (1994) closely examined the engineering practices that engineers engage in different contexts and concluded that societal or complex technological problems cut across multiple disciplines, thus requiring collaboration among experts from a wide range of disciplines to offer solutions to practical problems. In addition to complex engineering problems, time, and economic constraints along with ever-increasing specializations were considered as other reasons for the necessity of collective work (Anderson et al., 2010). Besides, several scholars claimed that the communication lies at the center of the design process as engineers engage in constant negotiations when selecting the most viable solutions, making engineering decisions, and communicating the design process and solution (e.g., Rittel & Webber, 1973; Trevelyan, 2014; Voland, 2004). For these reasons, engineering educators, philosophers, and historians described the engineering activity as a human social activity (e.g., Bocong, 2015; Meyers et al., 2010; Trevelyan, 2010; Vinck, 2003; Voland, 2004). Thus, one can easily say that the technical and social processes of engineering cannot be considered independently from one another. Social interactions, in fact, pervade each and every engineering activity.

The engineering design process is also a creative process in which novel ideas are essential to the creation process of innovative and artistic designs. Besides, the panel members stressed that facts and data are not all that engineers need but they also need creativity to push the boundaries. They also addressed the necessity of creativity to find design solutions to complex and complicated global problems. Likewise, van de Poel (2009) discussed that a certain level of creativity is required during the design process to produce innovative ideas. In the same vein, Dorst and van Overveld (2009) argued that engineers mostly engage in a creative rather than a deductive process as they transformed the ill-structured problem into well-structured ones. The studies, examining the views of the professional engineer as to the engineering profession, showed that practicing engineers considered thinking outside of the box as an important characteristic of successful engineers (Anderson et al., 2010; Dym et al., 2005; Trevelyan, 2010). It seems that the panel members of the study did not specify the necessity of creativity for particular engineering phases. On the other hand, Earle (1990) stated that creativity is required especially for idea generation and design refinement phases as in other phases, engineers rely more on empirical data than creativity.

The study indicated engineering solutions are bounded within a specific social context in which trade-offs have to be made as designs are bounded with various design constraints. From this perspective, even if engineers may have many viable solutions to a problem, they are working towards a sufficient, satisficing, or good enough solution because of specific design constraints. One panel member even called design solutions “ill-structured” solutions. As engineers cannot have the optimum of each quality, they have to make trade-off decisions to achieve a solution within a context with various design constraints. Therefore, the outcome becomes “sufficient” or “ill-structured”. Similarly, several scholars claimed that trade-off decision making is all about resolving value conflicts (van de Poel, 2009; Voland, 2004). In a similar way, scholars also underlined that because of various subjective elements and uncertainties, there may be multiple solutions (Dym et al., 2005; Jonassen et al., 2006). However, Simon (1977) explained this point such that engineers do not compare multiple viable solutions with one another. Instead, they often compare solutions with the design criteria and then, select the “satisficing” or “good enough” solution.

The tentative nature of engineering was another overarching theme that suggests that every element of the design process changes and in turn, needs to be revised during the design process. Iterations and revisions are often considered to be used in the design refinement phase in an attempt to improve or revise designs. However, it was evident in the panel members’ account that design specifications, engineering decisions, and even engineering problems can be reframed during the design process. Throughout the design process, new data and information can arise, engineers can encounter unexpected obstacles and failures at any point during the design process, renegotiations with stakeholders and clients regarding the design specifications can happen at multiple times during the design process or engineering problem can be found to be ill-structured at a later point in time because of inadequate knowledge that engineers have at the beginning of the design process. For all these reasons, the details of the design process need to be revised or reformulated during the design process. This is similar to what scholars called messy design work (Anderson, et al., 2010). The constant need for reframing engineering problems was also addressed by several scholars. Even if engineering problems are formulated very well, as engineers proceed through the design process, they can become ill-structured and they may need to be reformulated multiple times during the design process (Buchanan, 2009; Bulleit et al., 2015; Jonassen et al., 2006; Vermaas, 2015)

The study illustrated that the design process is also a reflective process. The panel members indicated that engineers need to reflect upon their engineering experiences and decisions throughout the design process and also, at the end of the engineering design process. They suggest that engineers need to make reflections based on empirical evidence and their design failures in order to make informed decisions for the next steps. Critical examinations on the whole design process is a necessary attempt to learn from design experiences. The panel members of the focus group made it clear that the design process as a whole is a reflective process. In this sense, reflective practices are considered important elements of the engineering activities by several scholars in the field of philosophy of engineering and engineering educators (Dias, 2014; Dieter & Schmidt, 2009; Earle, 1990; Voland, 2004). For instance, Dias (2014) discussed that engineering design includes both technical rationality and reflective practices that include making reflections upon professional practices. As this study showed, reflective practices on experiences yield practice-based knowledge or knowing-how.

Another important feature of engineering design that the study indicated was about the approaches that engineers take to generate engineering solutions. The panel members asserted that the basis of the design process is problem-solving; however, it was unraveled that the problem-solving is not the only activity that engineers engage in during the design process. Even though the panel members did not specifically define the design process as a decision-making process, it was clear in their statements that apart from problem-solving, they also use the decision-making approach throughout the design process. To be more specific, engineers use different sources of knowledge to gather information in order to decide on what a satisficing solution should be. They also collect empirical data to make a decision on viable solutions. They make trade-off decisions within various constraints. Besides, they make ethical and moral decisions in light of ethical obligations that their profession and organizations have in order to create solutions that do not harm people and the environment. In the same line of thinking, ABET (2018) which provides accreditation for college engineering programs stated that “it is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs” (p. 5). Likewise, Dym et al., (2005) and Kroes (2012) underscored the necessity of the decision-making process especially in selecting sufficient solutions and making trade-offs. They also claimed that engineering decisions are so critical in the design process that the outcome of the design activity depends on them.

Further, the open-ended nature of engineering was considered important for the design process. As previously mentioned, the iterative nature of the design process allows engineers to constantly optimize their solutions when they face design failures or fail to produce sufficient solutions within a design context. Along with that, several panel members suggested that the iterative nature of engineering is being used out of a specific design context. As noted earlier, the creation process should be considered in a more specific social context and a larger social context. Put it differently, this feature of the engineering design offers constant opportunities for engineers to maintain ever-changing clients/stakeholder needs. When clients, for instance, request improvement of the design in later years, engineers engage in iterative design to optimize their designs rather than starting from scratch. In a larger social context, it was observed in the accounts of several panel members that as society is not static but rather it is dynamic, its needs and problems are changing over time. To respond to the constantly changing needs, engineers optimize their already engineered artifacts through design iterations. Voland (2004), for instance, stressed that there is no perfect solution to a problem because engineers constantly engage in trade-off decision making to resolve the conflict among the values in order to produce sufficient design. For this reason, engineered design may require optimizations in the future to be able to design better. Hence, generating n-th generation of the design solution to a problem is a continuous and endless journey (Voland, 2014).

One of the questions that were asked during the first round of the Delphi study was about the values, norms, and rules of the engineering community. In light of panel members' statements, it was fair to conclude that engineering design is value-laden. This means that value judgments are the fundamental basis of the engineering decisions and thus, values are embedded in engineering artifacts. This finding received support from the literature on the philosophy of engineering. For instance, Steen and van de Poel (2012) asserted "all designs are driven by values." (p. 64). It was highlighted that engineering designs are value-laden. Put it differently, engineering designs are driven by values set by engineers, users, and/or companies (Steen, & van De Poel, I., 2012; Zwart et al., 2013). Therefore, values that are at play during the design process are what end-users will experience when they are interacting with it.

Out of values and norms, it was unearthed that ethical and moral values are paramount to the engineering community. The values including do not harm, integrity, and honoring intellectual property and sustainability were later named as ethical, environmental, and humanitarian considerations in light of the suggestions from the focus group participants. The outputs of the engineering activities have a direct effect on societal activities and relationships as well as the environment. Also, the panel members stressed, there are always, whether it is a small or large, risks associated with designs itself and how they will be used. In this respect, the panel members recommended do not harm value should be taken into consideration for everything that engineers design. The value of do not harm focuses on the idea that engineering designs are engineered in a way that they do not cause any harm to clients, society, and the environment. They care about anything that would be affected by design including not only humans but also animals, plants, air quality, etc. The panel members who are computer engineers/ educators underscored the importance of the privacy of people. In this respect, safety and risk analysis were considered an essential part of the engineering work. Relatedly, sustainability was considered to be the core values of the engineering community by several panel members of the Delphi study. However, several challenged this view as they stated that sustainability is not a pervasive value in the engineering community. On the other hand, the panel members of the focus group suggested the inclusion sustainability, considering K-12 student education. This value specifies that engineers need to find ways to reduce the impact on the environment taken place through the consumption of natural resources and waste production. In this sense, sustainability becomes an important responsibility for engineers to ensure a viable future for society.

Besides, it is worthwhile to note that the panel members also pointed out that tensions could arise between ethical principles and activities taken place within engineering organizations. To be more specific, engineers usually work in large engineering firms and thus, they are expected to serve and adopt their values rather than questioning their values. Sometimes conflicts arise when safety is compromised. One of the panel members of the focus group also endorsed this view by stating that engineers sometimes have to do things that they do not agree with. In this respect, the value of integrity comes into prominence.

Integrity was considered as a critical value for the engineering community in this study. As previously stated, engineering is a high impact discipline which means that while engineered designs shape society and the world around us but most importantly, its adverse effects on society and the environment could be detrimental. In that matter, engineers need to be honest and trustworthy regarding ethical issues. Given that engineering designs are fallible, the calculations and analysis should be carried out in a transparent manner. Several panel members stressed the necessity of using empirical evidence to ensure that their designs and judgments do not violate ethical standards. That's why empirical evidence was also considered as a norm of the engineering community. Integrity was regarded as a vital moral virtue for engineering by the panel members. In this context, the engineers' responsibility is worth mentioning. The panel members underscored engineers' own moral responsibilities beyond ethical obligations or legal responsibilities. Most panel members concur that engineers should bear the possible outcomes and consequences of their designs into their minds. On the other hand, one of the panel members expressed concerns about the overemphasis on engineers' responsibilities with regard to the social implications of their design. Put it differently, the panel member contended that engineers need to follow objective ethical and safety standards; however, they tend not to take further responsibilities. Relatedly, this issue has long been debated by philosophers of engineering/technology. Some claimed that the impacts of engineering designs are dependent mainly on how they are being used and maintained by end-users (Ambler, 2015). Some even justified that engineering design is value-free or neutral (van de Poel, 2009). Therefore, values of engineering designs are designated based on the values of end-users, that is to say, external values. On the other hand, others advocated that internal values or engineers' own values are important to engineering designs and they further claimed that engineers need to accept responsibility for their own actions (Gunn, 2010; Meyers et al., 2010; Zwart & Kores, 2015).

Engineers' responsibility gains in importance especially when ethical dilemmas or conflicts arise. Engineers working in larger companies or organizations sometimes experience those ethical dilemmas and it becomes complicated to resolve conflicts. In this case, many panel members advocated that it is the engineers' responsibility to stand up as much as possible against any kind of safety and ethics violations. In the literature, this was called "whistleblowing" (Johnson, 2017) or "rebellious ethics" (Meganck, 2015) which means standing for their beliefs and against any activity that violates safety and ethical standards. Johnson (2017) regarded whistleblowing as one of the social responsibilities of engineers.

Although honoring intellectual property was first considered as one of the aspects of the value of integrity, some participants suggested considering it in a separate category due to its importance to the engineering community. This theme focuses on the idea that given that multiple individuals are working in an engineering project, it is necessary to properly acknowledge the contributions of others.

It is worth to note that as one panel member argued that ethical and moral values are not fixed but rather vary across social, cultural, and political systems. In this sense, scholars examining the core values of engineers in different countries indicated their primary concerns indeed differed depending on their unique historical and cultural values (Anderson et al., 2010; Downey et al., 2007; Poser, 2013)

Besides ethical, moral, and social values, the technical values are also important to the engineering design. This study illustrated the value of functionality as a core of the engineering community. Functionality is related to whether engineering artifacts function as intended. It was regarded as a very substantial value at play during the engineering decision-making process. If artifacts do not fulfill its practical use, that is to say, do not work properly, they have failed.
In a similar vein, several scholars viewed it as a core value that was used to determine whether the engineering design succeed or not since every engineering design is produced for a particular practical use and every design process is mainly guided by practical rationality (Bucciarelli, 1994; Nightingale, 2009; van de Poel, 2009; Vincenti, 1990). One of the panel members suggested the inclusion of effectiveness and efficiency as they are related to the value of functionality. With that in mind, van de Poel (2009) suggested that effectiveness and efficiency are two important values that can be utilized as two measures to assess whether the design optimally achieves its practical end. Effectiveness was described as the degree to which the design optimally functions as intended while efficiency was considered as the ratio between to what extent the design achieves its function and the effort needed to ensure that effect. Hence, these two values should be addressed in relation to the value of functionality.

One panel member of the Delphi study, although did not provide a detailed explanation, mentioned that in the idea generation phase, engineers need to interpret the qualitative statements of goals/purposes and translate those into concrete quantitative specifications. On the other hand, van de Poel (2009) touched on how values are translated into concrete design requirements is worth mentioning. In this respect, the design values are first described as functions, features, or properties. Given that design requirements guide the design process, the next step is to develop more detailed information that is provided concerning what and how actions should be done to fulfill the design requirements.

Another theme related to the values of the engineering community was identified as the contextual values in engineering. Apart from the ethical and core values of engineering, there are other values embedded in engineering decisions. These values were not pervasive values in engineering but rather are context-dependent. The panel member mentioned that different values come into play depending on the specific design context. Engineers usually work in organizations or engineering firms and they are expected to serve clients and the organizations that they work for. As stated earlier that engineers are expected to integrate their clients, stakeholders, and organizations' values in the design process. Therefore, some values could become important based on what clients’ needs and desires are. Those may include easy to repair, aesthetics, portability, and so on. Therefore, those values were considered as contextual values as their importance is contingent upon the specific social context. In a similar way, Anderson et al. (2010), studying with practicing engineers, indicated the organizations that engineers work within have a huge impact on what values engineers need to make decisions upon. There was a debate on this topic in the literature as some argued that many engineers work in private organizations that value financial growth rather than the betterment of society that limits the potential of engineering work for society (Newberry, 2015b).

In a similar vein, as regards to the value of desire to serve humanity, and later labeled as humanitarian considerations, there was a lack of consensus on whether this value was an integral aspect of every design work among the panel members. Some panel members advocated that each engineer should serve humanity and aim at improving society. On the other hand, several cautioned against the inclusion of this value as a core value applicable to all engineering designs.

As addressed in the literature of the philosophy of engineering and engineering education, there was a similar debate among scholars with respect to whether the betterment of society should be a shared value for the engineering community. In this sense, similar to the pattern observed in the accounts. Of the panel member, some scholars and accreditation documents for engineering programs suggested that engineers work for improving public welfare; however, several scholars advocated value-neutral morality for engineers and claimed that engineers need to focus merely on the universal ethical principles and do not involve in any other ethical questions concerning the betterment of society (Davis, 1998; Sheppard et al., 2006; van de Poel, 2010).

Besides that, some Delphi panelists indicated that engineers can create the design for just creation's sake, not necessarily to address an issue or a problem or they design to provide society with new power or convenience. In this sense, it was addressed that engineers' own values could become a decisive factor in determining which values should be integrated into engineering decisions. Relatedly, Vermaas (2015) argued, contrary to common assumption, that the role of engineers is not limited to addressing the desires and problems of clients or stakeholders. But in fact, the scope of the engineering design has changed from user-driven to designer-guided and designer-driven. This means that engineers are not merely attempting to address clients' problems or needs but they are also reframing engineering problems and design criteria to produce better products for their clients. Besides, there is also designer-driven engineering design in which engineers themselves frame needs to produce innovations which are also called game-changers or radical designs (Vermaas, 2015; Vincenti, 1990).

The issue of including the value of desire to serve humanity was further discussed with the panel members of the focus group and in light of their comments, it was decided to include this value as a contextual value.

All in all, most of the findings of the study showed consistencies with the claims of philosophers and historians of engineering/technology. Examining the aspects of engineering from the epistemological lens not merely enabled the researcher to identify the concepts important to the engineering discipline but helped the researcher unearthed the rationale behind why those concepts are essential to the engineering work. Consistent with the previous work on the philosophy and history of engineering, the current study identified the engineering discipline as a distinct way of knowing, thinking, and doing.

Discussions of the Findings of the Study in Light of K-12 Science and Engineering Education Literature

A series of policy-based reports recently underlined the need for high-quality engineering education in K-12 settings (International Technology Education Association [ITEEA], 2020; National Academies of Sciences, Engineering, Medicine [NASEM], 2020; National Research Council [NRC], 2009, 2014). NASEM (2020), for instance, highlighted the necessity of developing students' engineering literacy in K-12 settings. Engineering literacy was defined as understanding the key ideas of engineering and the ability to perform the design process to produce engineering artifacts as well as appreciating the effects of engineering on society and the differences between engineering and science. NASEM (2020) and ITEEA (2020) call for educators and researchers to integrate engineering as a way of knowing, thinking, and acting. In response to this call, the current study aimed to identify the nature of engineering knowledge, engineering design activities, and practices along with its values, norms, and standards.

The Delphi study indicated several epistemic aspects of engineering, some of which were in accord with previous studies and the suggestions of NGSS and several policy documents for engineering integration. On the other hand, this study also generated new themes and concepts that have the potential to extend the existing literature on K-12 science and engineering education. The following paragraphs were structured around the concerns arisen concerning the current view of engineering in science education standards to address how the conceptual framework developed in this study to address these concerns and how the findings of this study extend upon previous research in relation to K-12 engineering education.

Since the Next Generation Science Standards [NGSS] (2013) call for the integration of engineering design into science education, several concerns have been voiced by the science education researchers (e.g., Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017; Gunckel & Tolbers, 2018). The first concern was related to confusing language that was used throughout the standard documents (Cunningham & Carlsen, 2014). Please consider two following statements from the standard document:

> Engineering and technology are included as they relate to the applications of science, and in so doing they offer students a path to strengthen their understanding of the role of sciences. (NRC, 2012, p. 11)
>
> Engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science (NRC, 2012, p. 12)

The above arguments for the integration of engineering into science education could promote misunderstandings related to epistemology engineering. To be more specific, the Framework emphasized the use of engineering as a tool for the practical use and application of science. Likewise, Standards for Technological and Engineering Literacy [STEL] standards were proposed by ITEEA (2020) to guide the incorporation of engineering and technology in STEM education. For this reason, although the standards specified several characteristics of engineering along with technology, the main focus was on the use of these disciplines as contexts to make the connection among four disciplines more explicit in STEM education. The standards defined engineering as “engineering is the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under given constraints.” (ITEEA, 2020, p. 3). In a similar way, this definition oversimplifies engineering activities by narrowing them to the application of science and math knowledge in an attempt to produce practical solutions. Using engineering and technology as a context to promote STEM understanding is worthy of effort; however, it is my belief that it would be more productive if students are first introduced to engineering as a distinct discipline with its unique characteristics. After students develop a clear and comprehensive view of the full range of engineering ideas, it would be easier for them to appreciate the interrelation between the disciplines in STEM contexts.

In this sense, although this study indicated the fundamental roles of scientific knowledge in engineering activities, almost all panel members clearly stated that engineering is more than applied science which was also voiced by scholars in science education (Antink-Meyer & Brown, 2019; ITEEA, 2020; Pleasants & Olson, 2018). In addition, the panel members stressed that engineers need to know how scientific principles can be applied to engineering problems which are not the same level as the pure scientific level. Some panel members identified this form of knowledge as engineering science knowledge that is unique to the engineering disciplines. In addition, the current study indicated that the engineering knowledge base is multidisciplinary and interdisciplinary since many panel members placed emphasis that the knowledge about natural sciences is not the only knowledge for engineering activities. To be more specific, echoing the findings of the previous studies exploring the nature of engineering and engineering knowledge for K-12 science and engineering education as well as policy reports (Antink-Meyer & Brown, 2019; ITEEA, 2020; Moore et al., 2014; Pleasants & Olson, 2018), the current study demonstrated that mathematical and technological as the sources of the knowledge base of engineering. From this perspective, it seems that there is a general consensus on the interdisciplinary nature of engineering in the literature. On the other hand, the current study also underlined the importance of social knowledge. Since engineering is about designing for societal needs and creating a social change, engineers need to understand the social aspects of engineering including, but not limited to, human behaviors, how people interact with and experience with the end-product, social benefits, the social costs, the ethical implications, the environmental ramifications.

Some policy-based studies and research studies suggested the centrality of engineering design for engineering education since the engineering design is considered as the distinctive characteristic of engineering (e.g., Figueiredo, 2014; Moore et al., 2014; NGSS, Lead States, 2013; Pleasants & Olson, 2018). While engineering design is crucial to the engineering activities, overemphasis on the engineering design could mistakenly underestimate the conceptual aspects of engineering. This study illustrated that the engineering knowledge base is neither fixed nor limited to the knowledge obtained from other disciplines but instead the knowledge base is cumulative because of the engineering work itself. Learning from failures was identified as a norm by the Delphi panelists in this study. Design failures can highlight the limits of the design. This, in turn, informs future engineering activities and eventually contribute to the knowledge base of the community. Therefore, engineers learn not merely successes but also failures done in the past and failures that they encounter during the design process. Many scholars, likewise, indicated engineering knowledge base is not static but rather it is dynamic and evolving (e.g., Antink-Meyer & Brown, 2019; Sheppard et al., 206; Vincenti, 1990; Pleasants & Olson, 2018). Besides, this study pointed out the importance of practical knowledge. Several panel members argued that the knowledge about how to is what distinguishes engineering from other disciplines. It was stressed that although engineers may have a wealth of knowledge (science, mathematics, etc.), it is the knowledge about how to integrate that knowledge to engineering problems that make the difference. Also, they placed emphasis on the knowledge about how to perform design activities. In this respect, in the NGSS, three main disciplinary core ideas were identified for engineering concepts including "defining and delimiting an engineering problem, developing possible solutions, and optimizing the design solution" (NRC, 2012, p. 203). The three core ideas of engineering are framed as the activities that engineers engage in during the design process. It has merit to portray the engineering concepts as activities to emphasize the importance of practical knowledge or knowing-how. In a similar way, Cunningham and Kelly (2017) also advocated the inclusion of engineering as a set of practices on the account of "the ways that knowledge is constructed through action and practice" (p. 487). As Cunningham and Kelly (2017) stressed, practical knowledge develops by engaging in the design process, which was referred as experiential knowledge by the panel members in this study. The Delphi panelists argued that experiential knowledge manifests itself as a rule of thumbs or engineering judgments that engineers often rely on during the engineering activities. Therefore, the engineering design process should not be considered as a mere set of technical tasks that engineers perform but rather it is also a knowledge generation process. This is aligned with the notion of intelligent action proposed by Dewey (1974). Dewey put forward that intelligent action is different from blind trial and error process but rather it combines knowledge and practices together and they are in a reciprocal relationship-one always informs the other. Therefore, individuals benefit from their experiences and knowledge when taking actions and in turn, knowledge derived from their actions adds to their knowledge. Dewey also asserted that reflections made based on the experience and communication of them act as mediators of this practice-based knowledge. In a similar vein, the study revealed the crucial role of communication and reflective practices in the generation of knowledge.

As mentioned above, the NGSS conceptualizes the core ideas as practical knowledge. While highlighting the importance of practical knowledge in engineering, the current study considered the epistemic aspects of engineering as concepts to underline the significance of conceptual knowledge used in engineering.

In addition to the knowledge base of engineering, this study identified different engineering design phases, including problem definition, identification of design requirements and specification, idea generation, idea evaluation, and design refinement. It appears that the design model proposed by the study encompasses the NGSS suggestions on the core ideas of engineering. However, the study also revealed additional aspects of the design process.

First, the panel members stressed that engineers should obtain necessary information regarding the social, technical, economic, and ethical aspects of the engineering problem in the problem definition phase. The NGSS presents these aspects as constraints in the defining and delimiting engineering problems phase as follows: “constraints, which frame the salient conditions under which the problem must be solved, maybe physical, economic, legal, political, social, ethical, aesthetic, or related to time and place” (NGSS Lead States, 2013, p. 205). Viewing those aspects as constraints has merit; however, conceptualizing ethical and social aspects as mere technical constraints do not reflect the true characteristics of engineering as a discipline. This study showed that engineers have both technical and social concerns. This means that engineers need to consider whom they are designing for and possible end-user interactions and experiences in light of possible social and ethical implications of their designs. In other words, engineers have responsibility for the consequences of their own actions and care for anything that will possibly be influenced by their engineering design including humans, other species, environment, etc. It appears that the standard documents put a little emphasis on these social and ethical considerations in the optimizing the design solution phase (NRC, 2012). In a similar vein, Moore et al. (2014) proposed a three-phases engineering design model including "Problem and Background, Plan and Implement, and Test and Evaluate" (p. 4). Even though Moore et. al (2014) included ethical considerations as a dimension of engineering, those ideas were separately presented. Specifically, the descriptions of the design phases included mere technical tasks without the explicit emphasis on the social, ethical, economic, and political considerations. While it is important to place a special emphasis on ethical and social issues in engineering education, addressing the design process separately from its relevant ethical and social ramifications may falsely lead students to think that ethical and social implications of the design should be considered at the end of the design process. On the other hand, the panel members of both Delphi study and focus group concurred that those considerations should be embedded in all phases of engineering. In fact, one panel member of the Delphi study voiced that engineering design is one of many engineering jobs functions, but social and ethical considerations should be taken into account in each and every engineering activity.

Relatedly, this study indicated that engineering activities are socially embedded which I thought the NGSS fails to fully address. To be more specific, engineering work is shaped around their clients' and organizations' values and needs. From this perspective, the nature of engineering designs cannot be conceptualized independently from its specific social context.

Also, the panel members cautioned against any attempt to demarcate engineering from society and put a strong emphasis on the inseparable, transparent, and interdependent relationship between them. To be more specific, they expressed their concerns about the use of language when describing the role of engineering in society. Specifically, the phrase “interaction between science and society” could mistakenly suggest that they are separate entities. However, they recommended viewing engineering as an integral part of society. One panel member, for instance, argued that engineers should not be considered as aliens having an influence on society from outside. In that regard, the NGSS provides a very simplistic description of the relationship between engineering and society in the core idea related to the influence of engineering on society by focusing mainly on the reciprocal relationship between them, thereby missing the whole point of the social embeddedness feature of engineering. Besides, the NGSS addresses the discussions on social and ethical considerations only in grades 9-12. However, the panel members of the focus group underscored the importance of the inclusion of all these considerations into the design process starting from the elementary level in order to build habits of mind at the beginning.

Secondly, most engineering design models in the literature and standard documents such as the NGSS focus heavily on prototypical engineering systems. However, several panel members, in this study, made a useful distinction between prototypical and non-prototypical engineering systems. In non-prototypical engineering systems including structures (e.g., buildings, bridges, tunnels, etc.), the testing and evaluation process are qualitatively and quantitatively different than the prototypical systems such as machines. Further, in this study, value analysis was suggested to be an integral part of the design process to improve the features of products and reduce cost.

Besides, the current study demonstrated several prominent engineering practices including trade-off decision making, modeling, and iterations. In accord with the previous research on the nature of engineering and practices (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017; Pleasant & Olson, 2018), this study suggested that these core practices are at the heart of the design activities. Even though the NGSS standards included eight engineering practices, practices such as iterative design and trade-off decision making were not explicitly included among the NGSS engineering practices. The study also revealed the important aspects of engineering including empirical, multiple solutions, and failure-laden. In this sense, empirical and multiple solution aspects were also found to be important for the engineering design by the previous research (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017). On the other hand, this study provided additional insights into the features of the design process. To be more specific, the previous studies indicated that engineering designs and activities are based on empirical evidence. However, the current study also illustrated the empirical norms in engineering activities. The panel members suggested that engineers often rely on empirical evidence to eliminate any kind of human factor as much as possible. For instance, as one panel member stated if an engineer disregards factual information in the design process, empirical evidence is, therefore, required to ensure whether the design process is carried out according to the ethical principles. Also, several panel members stressed the importance of using empirical evidence to evaluate whether engineers adhere to the ethical values in their design. Furthermore, the panel members pointed up that design failure is an inherent feature of the engineering design process. Therefore, it can be inferred that the engineering design process is failure-laden. For this reason, it is necessary for engineers to develop awareness about the possible design failures in order to prevent them before they even become an issue.

Along with the above-mentioned technical elements of the engineering activities, this study illuminated that social and creative elements also constitute the essence of the engineering activities. Since the engineering activities are carried out in social contexts, social interactions with end-users/stakeholders, and collaboration with multiple individuals including engineers, experts from other disciplines, and laypeople are vital for engineering activities. This finding showed consistency with the previous research on the nature of engineering and several policy reports which suggested the critical roles of communication and collaboration in the engineering design (e.g., Cunningham & Kelly, 2017; Moore et al., 2014; NRC, 2009; NGSS Lead States, 2013). However, it is worth noting that as one panel member in this study cautioned that those social practices are not limited to the design process but rather engineers need to communicate and collaborate in almost all engineering activities. In addition, several of them emphasized that communication should not be viewed as a technical skill necessary to share and exchange technical information. Instead, communication should be considered as social interactions among multiple individuals by using various forms of communication which requires social skills.

Little work has explicitly addressed the significant role of creative insights in the engineering problem-solving process (Cunningham & Kelly, 2017; Deniz et al., 2019; ITEEA, 2020). The panel members, in this study, indicated creative insights are necessary to create innovations and find solutions to complex global problems. By the same token, Cunningham and Kelly (2017) argued that creativity is a required skill especially for realizing innovative designs. The researchers also highlighted the critical role of creativity in producing solutions, generations of multiple solution ideas, and learning from failures during the design process. Besides, Dewey (1930), an educational theorist, claimed that knowledge is not the only ingredient of the problem-solving process but rather imagination and creativity should be blended with the action (Dewey, 1930). Likewise, Kohler (2018), as a Gestalt psychologist, claimed that problem-solving was not a blind trial and error process, but instead, was a cognitive process in which creative insights play a major role in approaching problems through novel ways. Therefore, it can be concluded that creativity is an integral and essential part of the design process and it should be combined with each activity that engineers perform.

Unlike the past relevant studies, the findings of the present study provided further insights into the epistemic aspects of engineering. Firstly, the current study underlined the bounded nature of engineering solutions. Even though as previous work pointed out, engineers propose multiple solutions to a problem as there is no one right way to solve a problem (e.g., Cunningham & Kelly, 2017), the current study unearthed the bounded nature of engineering solutions or one participant called ill-structured engineering solutions. Each engineering design is specific to its social context in which various design constraints/specifications, clients' preferences come into play and trade-off decisions are made to resolve the conflicts among the values. For this reason, the engineering design process produces "satisficing" or in other words, "good enough" or "ill-structured" solutions.

Secondly, the tentative nature of the design process was revealed in this study. This overarching theme is related to the iterative and non-linear nature of engineering. To be more specific, engineers may need to revisit the phases of the design process through multiple iterations, indicating a non-linear model of the process. It was revealed based on the expert participants' accounts that because of this feature of the design process, each and every element of the design is subject to change. On the other hand, in the education literature, it was emphasized that the iterative process is only used for the purpose of optimizing and refining engineering designs. Consider the following statements from science education literature and standard documents:

> Engineering design is iterative, and design iterations necessitate testing and refinement. (Antink-Meyer & Brown, 2019, p. 548).
>
> Engineering design is both iterative and systematic. It is iterative in that each new version of the design is tested and then modified, based on what has been learned up to that point (NRC, 2012, P. 46).
>
> Design and problem solving are seen as iterative processes that involve idea generating, making, or building possible solutions, testing, and redesign (ITEEA, 2020, p. 21)…
>
> Almost any design is the result of a circular process (p. 52)

There is nothing wrong with the above statements but missing the whole scope of the iterative and non-linear nature of the design process. Specifically, the panel members of the study emphasized that the design elements and details including problem statement, design specifications, and requirements, viable solution ideas, etc. are subject to change throughout the design process. Engineers may need to reformulate their problem statements and change or update other design elements with the emergence of new information and data, and through renegotiation with clients/stakeholders. Also, several subjective elements such as subjective interpretations of design requirements, lack of necessary knowledge, etc. can also necessitate the reinterpretations and modifications of the design details during the design process. Therefore, contrary to the common assumptions in the literature, design iterations do not start in the refinement or optimization phase and iterations are not merely used to improve the design. Instead, iterations can begin as early as after the problem definition phase and can be also used to reformulate or update problem statements and design specifications or requirements. For this reason, in contrast to its common portrayal in curriculum materials, the engineering design process is far from being circular but rather it is messy.

Another important overarching theme revealed in this study was that the design process is a reflective process. Engineers constantly critically examine their actions during the design process. Based on every new information obtained from design failures and empirical data, they engage in iterations. The reflections on their experiences and new data inform their engineering decisions and how to proceed. Besides, several panel members suggested the reflections done at the end of the design process could inform the next design activities if learned from them. In this regard, a couple of past research suggested the integration of reflective practices in the design process for students' learning about engineering, although they did not address the reflective nature of the engineering design process (Moore et al., 2014; NASEM, 2020).

Further, the present study suggested that the engineering design process is not only a problem-solving but a decision-making process as well. Despite the fact that the Delphi panelists did not explicitly describe the design process as the decision-making process, it was evident in their accounts that engineers need to make numerous decisions during the design process. The participants stated that engineers need to gather information as much as possible to make a decision on the "satisficing" solution, that they need to make trade-off decisions to balance design criteria and constraints, and that they have to make ethical and moral decisions to produce designs that do not cause any harm to the environment and society and so on.

Lastly, the open-ended nature of engineering was unearthed based on the accounts of expert participants. The panel members illustrated that due to the iterative nature of the engineering design process, engineers can engage in a continuous process of improvement of their design. Put it differently, when needs arise, engineers make iterations to optimize their previous designs rather than going back to the drawing board. Engineering designs are socially embedded which means engineers creating solutions to social needs and those needs can change over time. To maintain the needs of individual clients, organizations, or society, they can use iterations. Therefore, it is fair to say that engineering designs are never finished and can be improved upon. In a similar vein, Antink-Meyer and Brown (2019) indicated the continuous improvement of engineering designs because of the advancements in science and technology. It was suggested that engineers use developments in the area of science and technology to continuously improve their designs.

The current study, unlike most studies in the science education literature, drew attention to the values and norms of the engineering community. It was evident in the panel members' accounts that ethical and moral values were paramount in the engineering community. Those values included do no harm, integrity, and honoring intellectual property. Do no harm (safety) was considered by the panel members as the most important value. Engineers are expected to adhere to certain ethical codes given that engineering is a high impact discipline which means that it has direct real-life influences on the environment and society. Also, panel members suggested the integration of those values in each and every activity of engineers. For instance, several of them suggested the use of risk analysis to anticipate the potential impacts of their designs. Besides, integrity was viewed as a core value of engineering because the panel members argued that engineers need to have moral responsibility beyond legal obligations.

In that respect, although it was revealed in this study that ethical and moral considerations are core values of engineering, the current science standards did not sufficiently address the ethical issues associated with engineering designs (NGSS, Lead States, 2013). In the standards documents, there are only two statements with respect to the committee's view on the inclusion of the ethical aspects of engineering in education as follows: “considerations of the historical, social, cultural, and ethical aspects of science and its applications, as well as of engineering and the technologies it develops, need a place in the natural science curriculum and classroom” (NRC, 2012, p. 248). In another statement, the standard documents advocated the incorporation of discussions around engineering design-related questions and ethical decisions. However, the standards neither elaborated on those ethical aspects of engineering designs nor integrated them into the engineering core ideas or practices. Within the scope of the core idea related to the influence of engineering on society, the standard documents addressed the potential adverse effects of technologies on society. To avoid those effects, it is suggested that engineers need to use benefit-risk analysis and models to anticipate the possible impacts of their design. However, the documents fail to discuss the ethical aspects of those impacts on society and the environment. In that respect, as discussed earlier, the present study recommended that ethical and moral considerations with regard to environmental and societal effects should be considered as an integral part of the engineering design process rather than seeing them external to the design process. In other words, ethical and moral considerations should be infused throughout the design process instead of discussing them at the end of the engineering design activity. Also, the panel members of the focus group concurred that those considerations should start as early as the elementary level, not in high school. The panel member suggested that the level of complexity of ethical and moral issues could be different across grade-bands.

In science education literature, similar concerns have been raised by several scholars (Antink-Meyer & Brown, 2019; Gunckel & Tolbert, 2018). For instance, Gunckel and Tolbert (2018) expressed concerns with respect to the overemphasis that the NGSS puts on the technocratic perspectives, undervaluing the care and moral dimensions of the engineering discipline. They criticized that the NGSS with its current focus portrayed engineering as a profession that assumes no or little responsibility for the impacts that their designs have on society and the environment. From this perspective, they recommended the introduction of issues such as inequality, harm, and ecological instability. Similarly, several panel members mentioned engineers care for anything that will be affected by their actions. Therefore, the present study reinforced the previous research in terms of the inclusion of integrity as a core dimension of engineering.

Besides, Pleasant and Olson (2019) pointed out the controversy among scholars over how much responsibility engineering should take for the impact of designs. They indicated that although many scholars must assume more responsibility apart from ethical obligations, there are scholars who thought that it is difficult to anticipate future effects. There were some disagreements among the panel members concerning this issue. Some suggested that there are ethical obligations that engineers have to follow; it is unreasonable to expect more from them. However, the value of integrity received high consensus among the panel members across the rounds.

As regards the ethical and moral values, although not specific to the engineering education, several scholars in science education also discussed the necessity of the infusion of ethical and moral values into education on the grounds that scientific literacy requires individuals to make informed decisions regarding environmental and societal issues (e.g., Dolan et al., 2009; Frazer & Kornhauser, 2014; Zeidler, 1984). Therefore, the present study suggested more emphasis should be given to ethical and moral values, together with the responsibilities of engineering in order to improve students’ engineering literacy.

As previously stated, several scholars in the science education literature advocated the incorporation of the ethics in engineering curriculum; however, they did not provide comprehensive descriptions as to these ethical and moral considerations and how to integrate them in the engineering activities (Moore et al., 2014; Antink-Meyer & Brown, 2019). In that sense, this study provided clear descriptions of the ethical and moral dimensions of engineering.

Apart from the core ethical and moral values, the current study demonstrated that values of the engineering community could vary across contexts depending on designers' intended values, clients' or organizations' aspired values, etc. As panel members discussed, engineers aim to serve their clients and institutions in which they work. For this reason, clients' and organizations' values and needs are decisive factors on what values should be at play in making engineering design decisions. Of the values of the engineering community, desire to serve humanity was one of the most debated values among both the panelists of the Delphi study and the focus group. It was discussed whether this value was a pervasive one in the engineering profession. While several Delphi panelists viewed humanitarian considerations and efforts as a core value or thought it should be, others argued that it does not reflect the work and values of all engineers or engineering institutions. Also, the expert panelists discussed that engineering is not always concerned with the needs and problems of society but that they are often motivated by creating new convenience or by technical problems. Therefore, the panel members requested to exclude it from the list.

This is where the discussion of whether we, as educators, should address humanitarian values in the K-12 context is of importance. Relatedly, Garibay (2015) reported that of 6100 STEM undergraduate students, only 17% of students thought that working for social change was essential to their career path. Garibay argued that K-12 students, before entering college, should be engaged in discussions around social issues in order to develop a sense of social and civic responsibility. During the study, whether the value of desire to serve humanity should be part of K-12 education was further discuss with K-12 educators in the focus group meeting. During the meeting, it was contended that this value was an important aspirational value that should be addressed in K-12 classrooms as it could motivate many students. On the other hand, it was also argued that this value may not be relevant to the interests of all students and other values such as more technical values and work should be also addressed. Similar to that, several panel members of the Delphi study discussed the need for diversity in the engineering profession in terms of capabilities and interests. Some engineers have sophisticated technical skills, or they are more inclined to technical work while others, for instance, are more interested in improving people's lives by working in Engineering Without Borders organizations. Therefore, the researcher decided to reinclude the theme of the desire to serve humanity to the list but considered as a context-dependent value.

Besides, one of the core values of the engineering community was identified in this study as functionality. Engineers are mainly concerned with whether their designs fulfill the desired function. Likewise, Pleasant and Olson (2018) highlighted that the primary purpose of engineering is to produce functional technologies that was the main characteristic of engineering distinguishing engineering designs from non-engineering ones. In addition, one panel member made a useful distinction between form and function. In contrast to common belief, forms do not always follow function due to the multi-valued characteristics of engineering designs. Put it differently, engineers try to match form to function during the design process; however, functionality is not the only concern in a design process since as discussed earlier, multiple values come into play. Thus, each form can have many functions and each function can take many forms. Also, it was underlined that there was no one universal definition as to what the desired function for engineering designs since it is constructed by engineers during the design process.

Overall, the current study indicated engineering, as a distinct discipline, has its own knowledge, ways of doing, values, standards, and norms. However, the current science standards oversimplified the distinct characteristics of science and engineering by focusing only on the difference in their purposes and end-products. Also, the current inclusion of engineering within science education programs could easily promote misconceptions among students as well as teachers concerning engineering being an applied science or engineering being one of the subdisciplines of science (Cunningham & Carlsen, 2014; McComas & Nouri, 2016). For this reason, it is deemed required to clearly establish the distinctions between engineering and science, considering the differences in their practices, knowledge, values, norms, and standards. However, it is noteworthy that as Newberry (2015b) pointed out, it would be a vain attempt to conceptualize engineering as an ontologically distinct entity since as this study also illustrated that engineering is an interdisciplinary profession that has both unique features and features that may intersect with other disciplines. For instance, creative insights are not only invaluable to the engineering profession but also to many other disciplines. Thus, it is critical to stress both similarities and differences between science and engineering in science instructions to develop a more accurate understanding of the engineering discipline.

Implications

The necessity to develop engineering literacy for K-12 students has been recently acknowledged by several policy-based reports (ITEEA, 2020; NASEM, 2020; NRC, 2014). In this respect, it is a necessary step to identify the core features of engineering to promote engineering literacy. The overarching aim of the current study was to provide a more holistic and complete view of the engineering for K-12 science and engineering education. Unlike previous studies, the study sought insights from engineering educators, scholars studying the philosophy and history of engineering/technology and practicing engineers in order to identify the epistemological underpinnings of the engineering discipline. From this perspective, the significance of the current study lies in the fact that it provided agreed-upon epistemic aspects of engineering based on empirical data acquired from experts in the field of engineering.

This study illustrated that engineering with its own way of knowing, thinking, and doing is a distinct discipline that merits a special emphasis in the K-12 science and engineering instructions, curriculum, and standards as well as teacher education. Hence, the following implications will be of interest to K-12 science and engineering teachers, teacher educators, and policymakers.

After the inclusion of engineering in the K-12 science programs, several concerns have been raised with regard to the inaccurate and incomplete presentation of engineering in the standards (e.g., Antink-Meyer & Brown, 2019; Cunningham & Carlsen, 2014; McComas & Nouri, 2016). In response to these concerns, this study explored the underpinnings of the engineering discipline to identify key features of engineering. It is of my belief that exploring productive epistemologies of professional engineering provided a broader understanding as to what counts as engineering. From this perspective, I suggested that the epistemic aspects of engineering should become a core part of the science and engineering curriculum in order to offer a more accurate and complete view of engineering.

Another concern for the view of engineering in the standards is the overemphasis on procedural knowledge- core knowledge with respect to the engineering design phases. As has been shown, the procedural knowledge alone is not sufficient to develop disciplinary knowledge (e.g., Antony, 1996; Bell et al., 2003; Sandoval & Morrison, 2003). To understand the logic and rationale behind why things happen in the way they do, students need explicit and reflective instructions on the concepts that characterize what and how knowledge is used, how practices are carried out within the discipline and what values and norms are adopted by the members of the community. That is to say, the aim of this study was not to provide a mere list of key epistemic aspects of engineering, but to provide explanations why those practices, forms of knowledge and aspects are an integral part of the engineering activities. In that sense, instead of a mere discussion of what the key epistemic aspects of engineering are, it is critical to point out the ideas behind those concepts. For instance, rather than simply introducing that there could be multiple solutions in engineering, it is vital to address that the reason for this is that subjective elements play a role in the design activities. Those elements included that engineers often deal with ill-defined engineering problems and engineering solutions are often not single-valued but many values could come into play during the design process depending on the specific engineering context. Therefore, this study suggested that explicit and reflective instructions on the epistemic aspects of engineering not be considered as a separate component of engineering instructions but rather those concepts should be embedded into engineering design activities to help students make sense of their engineering design experiences.

Besides, the findings of this study indicated that the themes were interconnected in many ways, thereby suggesting that the themes should not be regarded as independent and distinct epistemic aspects. The overarching themes, therefore, could provide a more holistic view of the epistemology of engineering. For example, the socially embedded aspect of engineering illuminates why ethical and moral values are vital to the engineering community.

Along with the theoretical implications, the study also offers practical implications for pre-college engineering education. To be more specific, the aspects found in the study should not only be taken into consideration as concepts that need to be introduced in engineering instructions, but they have the potential to be used as a conceptual framework to guide and promote the engineering design activities as well. First of all, this study demonstrated that engineering as an interdisciplinary profession uses different forms of knowledge along with its unique forms of knowledge (practical knowledge and engineering science knowledge). Engineering work is not only related to uses of science and mathematics principles but more to creating a societal change and often societal improvements through technology. In this respect, instead of focusing merely on the use of science and mathematics knowledge, learners should be encouraged to integrate social knowledge in the design process, considering human behaviors, social needs, social costs, the ethical implications, the environmental ramifications, etc. Another important source of knowledge for engineering is for technological knowledge. In this regard, it would be beneficial for learners to develop an understanding with respect to how existing technologies work as a part of engineering activities.

It has to be noted that the study emphasized that engineers do not merely analyze the knowledge necessary to produce solutions, but they also need to synthesize that knowledge to be able to use it for practical purposes. It is, thus, necessary to help learners focus on how science and math knowledge and other forms of knowledge could be used for design.

Along with science, math, social, and technological knowledge, as this study demonstrated practical knowledge (or knowing-how) constitutes a substantial part of the engineering knowledge base. Knowing-how mostly is derived from practical applications, or in other words, engineering experience. For this reason, it is also necessary to emphasize the importance of practical knowledge in the design process given that engineers sometimes rely on their experiential knowledge, or it is also called the rule of thumbs and engineering judgments. In this sense, this knowledge production feature of engineering should be highlighted during the design activities as learners learn by doing. Learners should be guided to examine their own design experiences. That is to say, they need to communicate technical analysis, how the design was optimized, how it was tested, implemented, and monitored, and how it should be. Besides, the cumulative nature of the engineering knowledge base is another important aspect of engineering that should be stressed. As the study's participants showed that engineers constantly learn from their own and others' engineering design experiences as well as past successes and failures that eventually contribute to the knowledge base of engineering. Therefore, it should be emphasized that the engineering knowledge base is not fixed but rather it is expanding.

Learners should have explicit discussions on the role of technical and non-technical elements in the engineering design, but educators should make sure those elements are integrated into the design activities. The study illustrated that communication and collaboration are the backbones of engineering activities. A substantial part of the engineering work involves collective work and communication. Therefore, it has been deemed necessary to engage learners in collaborative engineering works in which they can collectively generate solution ideas and communicate with each other. Another important element was shown that engineering design is a creative process in which creative insights play a crucial role. Thus, learners should be encouraged to engage in novel ideas rather than focus merely on replicating what is already designed. As for the technical aspects of the design process, the study proposed a five-stage design process, including a set of requirements to effectively perform the design process. The design process indicated two different types of engineering design: prototypical and non-prototypical engineering systems. Both design systems differ in terms of required design practices and elements. It is, thus, necessary to engage learners in both design processes. From the practitioner viewpoint, while young students could be engaged in prototypical engineering systems, high school students could be given the opportunity to create conceptual designs (e.g., technical drawings, models, etc.) for non-prototypical design systems. Additionally, several practices crucial to the design activities were underlined in this study. In this regard, the following practices should be more explicitly emphasized in the design activities: decision-making processes including trade-off decision making and decisions on the viable design solution, modeling practices, empirical data collection and testing.

Another important finding was related to the bounded nature of engineering solutions. Given that engineers have to make trade-offs between variables and deal with various design constraints, they need to work toward a satisficing solution rather than generating the best solution to an engineering problem. For this reason, even though students may have multiple solutions, it is important to guide them to compare their solution ideas with the design specifications rather than comparing their ideas with other viable idea solutions in order to generate a satisficing or good enough solution.

Further, this study suggested that the engineering design process is a nonlinear process that involves constant iterations. As the panel members who were engineering educators at higher education institutions recommended that introducing the design process as distinct stages have merit because it helps describe the details of the phases of the design process, together with its guidelines and rules; however, it may easily cause misunderstandings among learners. They may think that the engineering design process is a linear process or a repeating loop. In this sense, the tentative nature of the design process could be useful to understand the nature of iterative and non-linear design processes. In the process, revisions and iterations generally do not start in the design refinement stage but instead, it starts as early as when engineering problems are defined. Engineering design problems may need to be reformulated as engineers proceed. In this sense, learners should be encouraged to be open to any changes or modifications of engineering problems, design specifications, and other elements of the design process when new data or information arises during the design process. It should be emphasized that the actual design process that professional engineers engage in is far from being a sequential path or a loop but rather it is a messy process and most of the phases are carried out simultaneously. That is to say, engineers usually do not strictly follow steps but rather they determine what needs to be done next.

Relatedly, as an overarching theme, reflective practices are an essential component of the engineering activities as reflections are what moves engineers from one iteration to another. But also, it is essential for each and every part of the design process. Engineers need to critically examine every action they take and design failures as well as data to be able to determine what they need to do next. As for the class implementations, to engage in reflections, learners should use communication norms through which communication can be translated into more concrete forms. Those include, but limited to, drawings, data, calculations, actual blueprints, models, schematics, documents including technical information, and detailed records of their discussions, decisions, and thought processes. On the other hand, this study also recommended that reflective practices not only can play an important role to move the design process forward but also hindsight reflections on the whole design experience can provide opportunities to learn from the past experiences. Especially, learners should be guided to learn from design failures by highlighting the design limits that they encounter during the process.

As the study suggested, engineering decisions are value-laden. It is, therefore, important to make values explicit during the design process so that learners appreciate the values that the engineering community places importance on instead of viewing them as mere technical criteria and constraints. It was emphasized that engineers have both technical and social concerns. First, engineers are concerned with the functionality of their designs, in other words, whether their designs fulfill useful functions. As a core value, the functionality of engineering designs should be integrated into engineering design projects. Besides that, engineers are concerned with the social implications of their designs since it is a huge impact discipline. Accordingly, the present study recommended that ethical and moral values should be integral components of each engineering activity. It would be wise to engage learners in risk/benefit analysis when defining their problems, evaluating their idea solutions, and refining their designs. The ethical, environmental, and humanitarian considerations could raise awareness among learners concerning the social responsibilities that engineers have. However, it has to be noted that every profession has flaws and in engineering, there are sometimes conflicts between ethical guidelines and the actions of engineers or engineering firms. To portray real-life practices of engineering, the tensions between values should also be addressed in the classroom (e.g., ethical dilemmas). On the one hand, this could be a great opportunity for learners to learn what engineers deal with in daily life alongside the ideal image of engineering. On the other hand, touching on these conflicts could provide a context in which the discussions could be held on how an engineer should act in these circumstances, together with the emphasis on the importance of the ethical and moral responsibilities that engineers have for their actions. Lastly, the study advocated that those considerations should be integrated into design activities at all levels of education from elementary to the high school level to build habits of mind. The level of complexity of ethics and social issues should be determined, considering students' moral development stages.

This study illustrated that engineering activities cannot be considered as detached from their social contexts. In this respect, discussions held on the importance of social context in a classroom environment would not be sufficient to help learners appreciate the deep connections between engineering and society. Several panel members, in this study, discussed the benefits of having novice engineers engage in local engineering projects. In those types of projects, learners can communicate, interact, and collaborate with the members of the local community to identify their needs and problems and then, find a solution that will benefit the local community. Thus, learners could come to understand how engineering activities are performed in a social context, taking into consideration social needs as well as the social and environmental implications of their designs. Also, these kinds of projects help educators to provide authentic design experiences for learners.

Relatedly, the current study recommended that the desire to serve the local community and humanity should be regarded as a context-dependent value of the engineering community. As discussed in the study, the engineering profession should be portrayed with both ideals and real-life practices. Put it differently, students should be introduced that engineers are concerned with the betterment of society and aim to develop solutions to solve human problems and improve the quality of peoples' lives. On the other hand, not all engineers or engineering firms are motivated by serving society but instead, they sometimes design for creation's sake. Those are more interested in the technical side of engineering rather than the human or social side of it. As shown in the study, engineering work requires diversity in this sense. To broaden student participation, educators should address both sides of engineering practices. Besides, most engineers serve clients and engineering firms or organizations and thus, have little or no control over determining what values should be integrated into the design. Therefore, it is essential to present experiences that engineers have in real-life professional contexts in order to help students more consciously make decisions about future engineering careers.

Lastly, it would be beneficial to compare epistemic aspects of engineering with those of science to deepen students' understanding of the nature of these disciplines. In that regard, the study suggested addressing epistemological underpinnings of them, emphasizing how knowledge is used, how practices are carried out within the disciplines, and what values, norms, and standards that engineers and scientists adopt.

All in all, the present study could extend the current knowledge base on pre-college engineering education by providing a conceptual framework that illuminates the key epistemic aspects of engineering. The findings of this study with its proposed themes and overarching themes with respect to epistemic aspects of engineering could be invaluable for teacher preparation, professional development programs, and for those who are concerned with enhancing their daily classroom practices. To be more specific, bearing in mind that the inadequate knowledge that teachers and students held about epistemic aspects of engineering, such a conceptual framework could not only help students and teachers develop disciplinary knowledge for engineering but also assist teachers and teacher educators in designing engineering design activities. In addition, the theoretical and practical insights that the study provided would be of interest to K-12 curriculum developers and policymakers who are seeking to leverage the full potential of engineering education and improve students' engineering literacy.

Limitations of the Study

The nature of the Delphi methodology does impose several limitations. As is typical in Delphi research designs, the Delphi process may have had an influence on the opinions of experts. In particular, the themes initially suggested by few panel members received high consensus in the subsequent rounds and the themes initially suggested by more than ten panel members did not meet the consensus criteria, thereby excluding from the list. Also, the descriptive statistics including mean ratings and standard deviations for each theme presented in the last round might have influenced their views.

Besides, it was argued that Delphi researchers may affect the opinions and views of expert panelists (e.g., Blanco-López et al., 2015). To be more specific, the initial open-ended questions might have influenced the thoughts of the expert panelists. Due to this issue, the interviews were conducted with seventeen panel members (56.67% of the total participants) to elaborate on their answers. During these interviews, they were also asked whether they had any additional suggestions or opinions concerning the features of engineering. Another point can be raised with the qualitative analysis performed after the first round. The first stage of the Delphi process included a qualitative data analysis through which the researcher created and categorized the themes. As previously noted, even though the researcher made an effort to stay close to the data as much as possible, the themes inevitably represented my interpretations. First, as a constructivist interpreter researcher, it is of my belief that the knowledge is co-constructed by the researcher and the participants. Secondly, the researcher paid special attention to the expert panelists' comments on themes during the Delphi process as those comments often guided not merely in the revisions of the titles and summary statements, and the addition and selection of the most important themes but the comments also assisted the researcher to generate theoretical codes.

As for the participation in the Delphi process, even though there was a high rate of participation in Round 1 (*N*= 30), only 19 of the 30 panelists participated in Round 2 and 16 of the 19 of them took part in Round 3. The relatively lower participation rate in the last two rounds might be related to attrition. Put it differently, the length of the process and/or a lengthy list including more than ten themes might be burdensome to several expert panelists, which in turn, might have led to high attrition between rounds. On the other hand, it should be noted that the data were collected in Round 2 and 3 during the COVID-19 pandemic and several participants, in this regard, informed the researcher that the reason why they could not attend the study any longer was the situation that they were in due to pandemic. Although fewer participants filled out the questionnaire in the last rounds, the study reached the optimum number of experts which is between 15 and 25 (Hsu & Sandford, 2007).

While the expert panel included engineering educators, researchers in the field of philosophy of engineering/technology, and practicing engineers, there were few experts in the field of history of engineering/technology and no sociologist of engineering. Further, most participants were from the U.S. and only four panel members (13.33%) participated in the study from different countries. In this sense, the study's expert panel was not as inclusive as was initially claimed.

Considering the above-mentioned limitations of the present study and the inherent features of the Delphi method, I do not consider the findings of the study as being final or definitive. On the other hand, given the fact that every methodology has its own limitations and every individual has different realities, no one group of individuals or methodology is able to offer definitive explanations regarding the key features of engineering. Therefore, I believe that my work or any other work should be considered as final or definitive but rather a contribution to a growing body of knowledge. In this sense, I believe that the findings of the current study could contribute to a better understanding of the epistemic aspects of engineering.

Recommendations for Future Research

This study has several suggestions with respect to several key areas for future research. Pre-college engineering education is still an emerging area in need of further investigation.
It is, thus, necessary for future research in pre-college engineering education to enhance our understanding of the epistemology of engineering as the basis for informing instructions, curriculum developments, and science and engineering standards.

Given that this study was the first attempt including inputs from practicing engineers and researchers in the field of philosophy and history of engineering/technology apart from engineering and science educators, more studies are needed to gain a more accurate understanding of the nature of engineering. It would be useful to inquire into views of experts from the fields of history and sociology of engineering. In addition, the expert panel of this study involved participants from four different countries; however, the geographical locations of the most of the experts were based in the U.S. Bearing in mind that although most of principles and theories of the engineering discipline are universal, as several scholars argued (e.g., Downey et al., 2007; Poser, 2013), societal, cultural, economic, and political factors have an impact on how practices are carried out and what values and standards that engineers engage in. In this sense, it would be wise to further investigate the core features of engineering, including engineers, philosophers, and engineering educators from different countries and cultures to provide further insights into epistemic aspects of engineering and eventually contribute to the pre-college engineering education.

Appendix A: Themes for the Epistemic Aspects of Engineering

	Epistemic Aspects	Descriptions
Knowledge Base for Engineering	Scientific Knowledge	Modern technologies that engineers work on frequently operate on the bases of physical laws and properties of matter. Engineers use the core principles of science and follow the latest advancement in science to understand how and why technologies and systems function the way that they do. Depending on the type of project/solution sought one of these sciences would become more important than another. But in all cases the science fundamentals are essential.
	Math Knowledge	Engineers need a strong background in mathematics in order for the proper application of underlying scientific principles and the performance, safety, etc. of the engineering solution. Engineers use the predictive capabilities of mathematics to base decisions on data and determine if a design is theoretically feasible. Also, the precision required in the design process demands certain types of quantitative analyses
	Technological Knowledge	Beyond basic science and math, engineers benefit from a working knowledge of parts, tools, materials and how existing technological systems work to engage in a meaningful design. The main reason why engineers need to develop a specialized knowledge of the technological systems is that engineers usually are not designing a new technological system or a process from scratch but rather modifying an existing one to meet a specific situation. Even if they design something novel, they need to know and understand technological systems, materials, etc. Also, they need to understand why a tool works the way it does because it is only once they develop this level of understanding that they can figure out how to do it differently. Therefore, with a good understanding of the technologies, they are able to choose the appropriate path in which to solve the problem.
	Engineering Knowledge	Engineers integrate science and math knowledge in the engineering design process (e.g., how basic principles are applied to engineering problems) to solve human problems and create innovations. The scientific and math knowledge differs in terms of specifics and are used distinctively in engineering disciplines. That is sometimes called engineering science knowledge.

		The knowledge from natural sciences is not all that is required to solve engineering problems. Engineers have the knowledge of the design procedure (the engineering design methodology), and technical principles that govern and constrain the design. Engineers benefit from knowing previous solutions to similar problems, how things have been done before, what things tend to work or not for a given type of application, what kinds of failures have been previously experienced. The knowledge derived from engineering experiences and observations such as when and how one should apply technical knowledge and methods could inform their judgements and decisions (e.g., rules of thumbs). Engineers produce solutions to social needs and problems in the engineering design process. For this reason, they should to develop an understanding of the social aspects of engineering including human behaviors, social benefits, the social costs, the ethical implications, and the environmental ramifications specific to particular engineering design.
The Stages of the Design Process	Problem Definition	In engineering design process, it is important to first identify the need, or what purpose does an engineering design need to be created and a define the problem which the design will address. Engineers need to gather appropriate information to more fully understand and define the problem in order to design a solution. Defining the problem requires consideration of a variety of aspects of an engineering problem; scientific, technical, mathematical, economic and social aspects. The boundaries of the design problem often become definitive as engineers work on the task, and specifications are often re-negotiated between clients/stakeholders at multiple points in time. Therefore, engineers remain open to altering and/or adding to the established problem over time during the design process. Problem definition is the most important stage which in many ways determines the direction of subsequent activities. A poorly defined problem will rarely produce an efficient solution. Many engineering failures can be traced back to a flawed or incomplete problem statement
	Identification of Design Specifications and Requirements	Engineers establish what the specifications and requirements of the design task are for possible solutions. This involves assessing resources, determining the main function of the product, as well as any objectives for the design, economic factors, expectations and constraints that bound the problem. In this stage,

	engineers interpret qualitative statements of goals/purposes and translating those into concrete quantitative specifications. Engineers in this stage develop an understanding of what would be considered a sufficient solution. They also consider the scientific, social, economic and ethical consequences of an acceptable solution. The specifications can be revisited and modified during the design process.
Idea Generation	In this stage, engineers engage in searching for existing solutions, brainstorming various solutions and sketching or modelling an example of a prototype (conceptual design-technical drawings) before coming up with the final design option. Engineers should ideally get multiple perspectives, so they should be open minded as being realistic about possible alternative solutions to the problem. Even though engineers engage in idea generation early in the process, idea generation tends to continue throughout the process as needed. Engineers searches for existing approaches since it is sometimes more feasible to use materials and approaches that already exist to build on existing designs (improvement/updating) or in order not to replicate someone else's design.
Idea Evaluation	As soon as ideas are generated, they are tested and evaluated to eliminate the ones that do not seem feasible or practical. This phase involves creating models and/or physical working prototypes, and conduct simulations in order to test and evaluate the design and determine whether the designs meets specifications. In For non-Prototypical systems where constructing a physical prototype is not possible, engineers construct models that can be used for the analysis of the system. Designers evaluate designs keeping in mind the scientific, technical, ethical and social aspects of what is an acceptable solution. This includes the analysis of the possible consequences that their products may have as well as feedback from others (e.g., clients, experts, community impacted). To narrow possible ideas down, a qualitative analysis which typically includes decision making matrices with ratings and rankings based on based on perceived qualities and drawbacks of various concepts is used. They simply evaluate them from physical, safety, economic, and user perspectives, until only a few solutions remain.

		Subsequent to the selection of an idea solution(s), engineers may need to create models or working prototypes to test the to test the feasibility of designs. The ability to make prototypes could reduce the level of uncertainty in the design process. Engineers use a formal evaluation with the agreed upon final prototypes. The evaluation should link back to the original functions, objectives, and constraints, while also allowing for the identification of unforeseen problems as well. In non-prototypical systems, instead of obtaining direct evidence from testing and evaluating physical prototypes, engineers employ quality control methods and peer reviews during the construction phase. Therefore, engineers obtain feedback from quality assurance as well as design failures.
	Design Refinement	Following evaluations of design ideas, solution ideas are either ruled out or gone through refinement or redesigning process. Engineers redesign or modify solution ideas when they encounter problems and failures through testing. Also, engineering design ideas are refined and optimized for economical production and for use by customers/consumers Engineers, in this phase, may conduct value analysis through which they can improve the features of products and reduce cost by teaming up with a multi-disciplinary team of experts including finance people, salespeople executives, and purchasing people. The iterations are performed until the "success" criteria are met. At the end of this phase, engineers communicate the solution.
Key Aspects of the Engineering Design Process	Communication	Communicating engineering problems and solutions are integral parts of the engineering discipline. Communicating problems is as important as communicating solutions during a design process as the problem statement may change over time, and engineers may need a better understanding of what they intend to do with their design. Engineers communicate effectively with multiple individuals, teams and/or companies. Communication within and between organizations are often critical to the success of engineering activities. Communication is also important to understand the needs and problems of customers/end users
	Collaboration	Engineering by nature is very collaborative. Many engineering works are executed as a team. Engineers even if they work alone, the results of their project are usually shared with the others. Engineers collaborate not only with

	other engineers but also with other experts from other disciplines including, but not limited to, finance people, salespeople executives, purchasing people as well as laypeople during and after the design process. Also, it is vital to be able to communicate and collaborate with client/user/those affected by the problem to really know whom they are designing for or the nature of the engineering problem
Multiple Solutions	There is no one single solution to a problem in designing. There may be multiple design solutions to a design problem, each with unique pros/cons as engineering solutions are not single-valued. Depending on the customers'/consumers' preferences, criteria, and design constraints, the solution could vary. However, it is important to acknowledge that engineers work under time constraints that come with their problem, so it does not feasible for engineers to invest too much time testing all solutions. Therefore, although engineers may have many alternative solutions at hand, they focus on the satisficing solution(s) due to various constraints.
Modeling	Modeling is an important part of the engineering design process, particularly in instances where prototyping is difficult or expensive. Engineers create virtual prototype models including engineering models, computer models and even the mental models that engineers have in their minds. Computer models/virtual prototypes help engineers conduct simulations
Empirical	Engineering solution ideas are evaluated through empirically driven tests. Engineers use facts and data to decide whether or not engineering designs perform as intended by quantifying design performance. Therefore, engineers find a concrete way to describe the sufficient or "successful" design. Also, engineers rely on empirical data when necessary knowledge is not available
Failure-laden	Failure is an inherent feature of the engineering design process. Engineers have to recognize design failures throughout the design process. It is rare to achieve effective solution the first time out since failure may have to occur before success is possible.
Creativity	Facts and data are extremely important, but so is creativity and pushing boundaries. Engineering method depends on creative insights in suggesting the solution to a problem. Engineering requires creativity and imagination to create innovative, new ideas and think of the artistic aspects of the design.

	Non-linear and Iterative	Even though there are several general rules and guidelines that allow novice engineers to engage in the design process, the engineering design process is not a formulaic, linear, step-by-step process. The iterative nature is typically driven by testing the effectiveness of individual aspects of designs. Due to the iterative nature of the design process, all engineering tasks occur simultaneously. Even final products are iterated because they are almost always revised and reintroduced. The reflection is the driving force to move the engineer from one iteration to the next as it is essential for engineers to consider what they have done and what they need to do next for a very intentional reason
	Trade-off decision making	Engineers cannot always have the optimum or sufficient amount of each quality. They are working under various constraints toward preferred design criteria. Therefore, the design process involves making tradeoffs between things (variables, etc.) in order to achieve a sufficient solution in a given condition
	Socially-Embedded	Engineering activities are shaped by social contexts within which they carry out. Engineers seek out what their customers/end-users' needs/wants in a product and they design products around those needs/wants. Also, engineers working in large companies are expected to serve them. They should to integrate their values in their engineering decision-making process. Engineering is just a manifestation of society and it is embedded. Therefore, engineering and society have been inseparable. As an integral part of society, engineers and engineering have an important role to play in society on a large-scale. That role is influenced by trends in societal, economic and political issues, both internal and external to engineering. In turn, technology, infrastructures, processes, and materials that engineers create shape society as well as social activities and relationships.
Values, norms and rules of the Engineering Community	Ethical and Environmental Considerations	**Do not harm** The societal and environmental impacts of engineering designs must be considered as a part of the design solutions to problems. The rules and values of the engineering community include codes and standards to maintain the engineering profession's ethical obligations for safety which means designing technologies that don't harm society and the environment. They should thoroughly evaluate the products of the design process with special consideration for any unintended consequence. **Integrity**

	Engineers must always act in a trustworthy and transparent manner during and after the design process when it comes to safety, engineering calculations, and ethics. Honesty about the process, specifications, safety, and objective analysis is important to the engineering discipline. They should follow the design process with integrity. For instance, if there is ever a doubt about the calculations or decisions, one should take extra precautions and not go ahead with a decision until the calculations can be double-checked. Also, engineers have the direct professional, ethical and moral responsibility to address unethical issues as well. Engineers have a professional responsibility to let people know about it, if the design is unsafe to use. Engineers should take responsibility to make an effort to consider the implications of their design. When ethical dilemmas or conflict arise, they should to stand up as much as possible **Sustainability** Engineers should consider environmental impacts and sustainability in their work. Finding ways to reduce the stress put on the environment by human resource consumption and waste production is an increasingly important responsibility for engineers in order to help ensure a viable future for society. **Honoring Intellectual Property** The engineering profession demands adherence to rules governing intellectual property rights. Engineers should not take credit for the designs of others or should properly attribute the contributions of others.
Functionality	Functionality is one of the core values for engineering discipline. Engineering designs need to mechanically function according to the laws of physics, for instance. Engineers determine what counts as “work” in the design process. Form and function of engineering designs should be considered on the same level to produce the most effective and efficient design. Effectiveness and efficiency could be considered as a measure whether the design fulfils its desired function.
Learning from Failure	Engineers have to recognize design failures and learn from them which can pave the way to success. Engineering knowledge advances by learning from failures because successful engineering design informs the future design, but failures can show engineers what does not work and why which enables engineers to exceed the limits of the design.

Empirical Norms	Engineers rely on empirical data to make engineering decisions and judgement. There is no place for hearsay or opinions in engineering. Engineers may need to rely on empirical data to ensure whether the design is designed adhering to ethical values
Communication Norms	Every profession, including engineering, has norms for communication, both formal and informal. The communication norms that engineers use include standard jargon and terminology, standard formats for engineering drawings and schematics, standard modes of writing and reporting technical information, etc. Such norms allow for the efficient and accurate transmission of technical information with a minimum of confusion and misinterpretation

Appendix B: The Overarching Themes for the Epistemic Aspects of Engineering

Overarching Themes	Descriptions
#1: The knowledge base of engineering is not the mere application of science	Even though scientific knowledge constitutes one of the sources of knowledge that engineers use, engineers need to transform and reconstruct knowledge about the natural world for practical purposes. Engineers need to make synthesis by bringing together knowledge from other disciplines
#2: The knowledge base is interdisciplinary and multidisciplinary by nature	Engineers call on knowledge from a wide array of disciplines throughout the design process. These different forms of knowledge including scientific, mathematical, technological, and social knowledge are integrated into the design activities.
#3: Practical knowledge is important for design activities	Practical knowledge constitutes a substantial part of the engineering knowledge base. In general, practical knowledge consists of knowledge about when and how to apply knowledge and execute the phases of the design process. The practical knowledge- rules of thumbs or intuitive understanding, derived from engineering design experiences often assist engineers in making engineering decisions. In this respect, experiential knowledge plays a major part in the development of this form of knowledge.
#4: The knowledge base of engineering is cumulative	The engineering knowledge base is continuously expanding as the knowledge developed in performing the engineering design process. Engineers constantly learn from their own design experiences as well as past success and failures. Therefore, the engineering knowledge base is not fixed but cumulative.
#5: Engineering involves both technical and non-technical elements	The technical elements of the design activities such as trade-off making decisions, iterative design process, optimization, and empirical evidence are important components of engineering work. On the other hand, engineering designs cannot be considered detached from their unique social context. Engineering designs emerge from collective work in a context of social interactions, communication, and conflict among engineers, stakeholders, and clients. In this sense, social activities including collaboration and communication are the backbone of the design activities. Besides, creative insights are invaluable to the creation of innovative solution ideas.
#6: Bounded nature of the engineering solutions	The aim of engineers is not to produce a perfect or optimal solution but rather a satisficing solution to a particular problem. Engineers need to make trade-off decisions between variables in order to meet the design criteria under various constraints. Therefore, they cannot have the

	optimum of each quality. From this perspective, engineers work toward achieving satisficing or good enough solutions. What counts as a satisficing solution is constructed by engineering in a specific design context. Thus, each engineering design solution is unique to the design context
#7: Tentative nature of the design process	Most of the engineering design details are subject to change during the design process due to the subjective elements and uncertainties such as lack of necessary knowledge, subjective interpretations of design requirements, etc. In this sense, problem definitions often change and take shape as engineers proceed through the design process. Design specifications can be renegotiated with clients and stakeholders. In this respect, engineers need to remain open to altering and/or adding to the established problems, specifications, and requirements throughout the design process. From this perspective, the design iterations are carried out not only for refining and improving the design products but also for restating engineering problems and reinterpreting other details. That's why the engineering design process should not be considered as a linear or a cyclic loop in which design phases are iterated in a stepwise manner but rather a "messy" process.
#8: Engineering design is a reflective process	During the design process, engineers critically examine their design experiences, which eventually serve as a tool to obtain feedback and learn from them. Engineers think over what they have done, communicate and determine what they need to do next for a very intentional reason. Also, reflections are done at the end of the design activities to critically examine what engineers did in order to possibly learn from it
#9: Engineering is not only a process of problem-solving but also a process of decision-making.	The basis of engineering design activities is on problem-solving. On the other hand, engineers need to make a wide range of decisions throughout the design process. They make decisions based on their knowledge and empirical data to evaluate whether a design option(s) fulfills the design criteria. They engage in trade-off making decisions in order to ensure a satisficing solution. Also, they engage in ethical and moral decision-making to ensure that their designs do not do any harm to people and the environment. Consequently, engineering decisions have a significant impact on end-product.
#10: Engineering design is an open-ended process	Engineering designs are socially embedded which means that engineering creates solutions to societal problems and needs. Therefore, engineers constantly engage in a continuous process of improvement of their design when

	new needs or problems arise. To maintain constantly changing needs and problems of clients and society, engineers often apply the iterative design process. Rather than starting from scratch, they can optimize their existing designs. In this sense, it can be said that the engineering design is never finished, and it can always be improved upon. Besides, given that the actual impacts of designs on the environment and society have been continuing to be revealed, engineers need to modify their designs to prevent the potential impacts of their designs on society and the environment
#11: Engineering designs are value-laden	Engineering decisions made throughout the design process are based on value judgments. Engineers decide what values should be at play during the design process. Ethical and moral values are paramount to the engineering design as every engineering artifact has certain risks that may influence society and environment in adverse ways. Functionality is another substantial value for the engineering design process. Technologies, processes, and systems that engineers design must fulfill their practical uses.
#12: Contextual values in engineering	Aside from the technical and ethical core values of the engineering discipline, different values come into play and become important in engineering design depending on the values and desires of the clients, organizations, and/or stakeholders as well as engineers' own intended values. Those context-dependent values could include aesthetics, easy to use, etc. The desire to serve humanity is an important aspirational aspect of engineering necessary to create solutions that solve human problems and are useful to society. However, this is not the only motive in engineering designs. Engineering designs can be built to provide people with some new convenience or power as well as to build creative innovations.

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Curriculum Vitae

Ezgi Yesilyurt
University of Nevada, Las Vegas

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Website: https://ezgiyesilyurt.wixsite.com/scientia
***ResearchGate*:** https://www.researchgate.net/profile/Ezgi_Yesilyurt2

Education

PhD Program in Science Education (2015-present)
University of Nevada, Las Vegas
Las Vegas, NV
Major: Science Education
Concentration: STEM Education

Master of Science in Elementary Science and Mathematics Education (2014)
Middle East Technical University
Ankara, Turkey
Major: Science Education
Concentration: Evolution Education
Dissertation: Conceptual, Structural and Epistemic Aspects of Science Teachers' Argumentation Practices in the Context of Evolutionary Theory

Bachelor of Science in Elementary Science Education (2010)
Middle East Technical University
Ankara, Turkey
Major: Science Education

Certification

K-8- General Teaching Certificate Science Endorsements

Scholarship & Awards

Sandra K. Abell Scholar (2019) - Awarded by the National Association of Research in Science Teaching (NARST) towards mentoring and supporting young scholars in developing their research agenda

Summer Doctoral Research Fellowship (2018-2019-2020) – Awarded by the UNLV Graduate College to support research activities during the summer term, $7000/yr, total $21,000

Jumki Basu Scholar Award (2019) – Awarded by the NARST Equity and Ethics (E&E) Committee to support graduate students' participation in the NARST conference

UNLV Graduate & Professional Student Association Conference Travel Grant (2016-2019), Awarded to support graduate students' participation in professional conferences University of Nevada, Las Vegas (2016-2019) $350/yr., total $1,400

Dr. Bea Babbitt Scholarship (2019) - Awarded for a record of accomplishment in science education, $1000

Graduate and Professional Student Association Merit Award (2019) – Awarded for "outstanding contributions towards the development and continuing growth of the GPSA at the University of Nevada, Las Vegas"

IMPACT Award for Community Engagement (2019)- Awarded for outstanding commitment to advancing learning and social change through organizing and providing Saturday STEM School workshops for elementary students

Edward Pierson Scholarship (2017-2018), Awarded for a record of accomplishment in science education, $1000/yr., total $3000

Professional Work Experience

Graduate Assistant, **University of Nevada, Las Vegas (2015-Present)**
Las Vegas, NV

Research Assistant (2015-Present)

Responsibilities include data collection and analysis of both qualitative and quantitative data and writing for publications

- **Research Project (2015-Present)**
  NSF-funded Project - Developing Integrated Elementary Science, Engineering, and Language Arts Curricula Aligned with Next Generation Science Standards
  Principal Investigator and Instructor of record Dr. Hasan Deniz
  -- Responsibilities include assisting in STEM workshops for elementary students in grades K 3-5, and science and engineering professional development programs for science teachers, and dissemination of results
- **Research Project (2018-2019)**
  NSF-funded Project-Collaborative Research: Teachers Engineering Project-based STEM Environments to Impact Diverse Learning Groups: Spanning Astronomical and Mathematical Spaces (Project SAMS) Principal Investigator Dr. Jennifer Wilhelm and Co- Principal Investigator Dr. Merryn Cole
  --Responsibilities include assisting in the preparation of materials and documents for the professional development program.

Teaching Assistant (2015-Present)

- **Instructor of EDEL 443/CIE 543 Elementary Science Methods (2016-Present)**

--Responsibilities include designing the course syllabus and teaching the course through inquiry with a special emphasis on the integration of science, mathematics, technology and engineering and literacy, and pedagogical content knowledge (PCK).

-**Assisted in the instruction of CIS 563-Teaching Secondary Science (2018-Present)**
Instructor of record Dr. Merryn Cole

-**Assisted in the instruction of EDU 202- introduction to Secondary Education (2017)**
Instructor of record Dr. Chia-Liang Dai

- **Assisted in the instruction of CIS 639 - Curriculum Development Secondary**

Science Education (2015)
Instructor of record Dr. Hasan Deniz
--Responsibilities included co-instructing the course and working with secondary science teachers in a science teaching course.

Researcher at the Center for Mathematics, Science and Engineering Education
Las Vegas, NV
Responsibilities included working on grant projects and developing workshops in collaboration between Colleges of Sciences, Education, and Engineering to enhance STEM education
https://www.unlv.edu/cmsee/staff

Instructor of STEM Saturday Program (2016-Present)
Las Vegas, NV
Saturday STEM program is designed to provide STEM education for the elementary and the middle school students in Las Vegas. This program provides grades 1-8 students an opportunity to experience a major STEM topic through a 5-week course in both fall and spring semesters
--Responsibilities included developing and providing STEM workshops.

Discourse Couching (2018-2019)
Las Vegas, NV
Project-funded by NV Great Teaching and Leading Fund: Argumentation and Learning in Secondary Science (Project ALSS) Principal Investigator Dr. Michael Nussbaum and Co-Investigator Dr. LeAnn Putney
--Responsibilities include supporting individual teachers (and teams) engaging more productive classroom discourse through teacher and student talk moves, lesson design and lesson implementation, observing individual teachers during the year, providing feedbacks, attending institute and group professional development sessions in which observing and leading small group discussions, and helping with lesson planning and critiquing.

Workshop Instructor of Robotics Academy of Nevada (RAN) (2019-2020)
Las Vegas, NV
The Desert Research Institute (DRI), UNLV, and the University of Nevada, Reno (UNR) are partnering with Tesla to help Nevada's teachers go from curious to confident in coaching robotics programs.
--Responsibilities include developing and providing STEM education-related workshops for K-12 teachers

Population Education Trainer (2019-continue)
Population Education is a national program with a strong emphasis on curriculum resources and professional development for K-12 educators that focuses on human population issues
-- Responsibilities include providing workshops annually for teachers and non-formal educators at conferences and in-service programs, as well as for future teachers in their education methods classes at campuses

Education Specialist in EPODIM (Educational and Professional Development through Innovative Methods) (2014-2015)
Ankara, Turkey

--Responsibilities included structuring and providing professional development programs funded by Amgen Teach European Program and Chain Reaction FP7 (European Union's Seventh Framework Programme). The program also involved on-site support for science teachers to implement inquiry and argumentation-based science teaching in their schools, analyzing survey and interview data, writing scientific reports.

Science Center Educator in the Children's Museum and Science Center (2013-2014)
Ankara, Turkey

--Responsibilities included designing and organizing science and engineering workshops for students (Grades 1-12).

Science Teacher in Private Cakil Tasim Education Center (2011-2013)
Ankara, Turkey

--Responsibilities included teaching science and mentoring elementary students (Grades 3-8)

English Assistant in Liceo Scientifico E. Majorana (2010-2011)
Rome, Italy

Comenius project, part of the European Union Lifelong Learning Programme
--Responsibilities included co-teaching English to high school students

Mentorship Experience

Mentee	Mentor Responsibilities	Dates
Mina Raeisi Undergraduate Student College of Education	Responsibilities include supporting and contributing to the professional development of the undergraduate mentee and leading the research projects, writing, and submission of the conference proposal to national conferences	2018-2019--The Graduate College Rebel Research and Mentorship Program (RAMP)
Nicole Thomas Master's Student College of Education	Responsibilities include supporting and contributing to the professional development of the master's student through insights regarding science education discipline and guiding the student creation of an academic paper	2020-Continue

Book Chapters

Deniz, H., **Yesilyurt, E.,** Newman, J. S., & Kaya, E. (in press). Toward a more robust nature of engineering conceptualization and instruction in K-12 Education. Critical Issues in STEM Education.

Deniz, H., **Yesilyurt, E.,** Kaya, E., Newley, A., & Lin, E. (under review). Integrating engineering, science, reading, and robotics across grades 3-8 in a stem education era. In K. G. Fomumyam (Ed.). *Theorizing STEM Education in the 21st Century.* IntechOpen

Peer-Reviewed Publications

Deniz, H**., Yesilyurt, E.,** Kaya, E., Newley, A., & Lin, E. (2020, April). Integrating Engineering, Science, Reading, and Robotics across Grades 3-8 in a STEM Education Era. In *Society for Information Technology & Teacher Education International Conference* (pp. 869-875). Association for the Advancement of Computing in Education (AACE).

Yesilyurt, E., Oztekin, C., Cakiroglu, J., & Deniz, H. (2019). Novice and experienced science teachers' conceptual knowledge of evolutionary theory within the context of micro-and macroevolution. *Journal of Biological Education*, 1-19.

Deniz, H., **Yesilyurt, E,** & Kaya, E. (in press). Teaching nature of engineering with picture books. *Science & Children*.

Deniz, H., **Yesilyurt, E**, & Kaya, E. (in press). Beyond engineering design: Teaching of the nature of engineering at the elementary level. *Science & Children.*

Deniz, H., Kaya, E., **Yesilyurt, E**, & Trabia, M. (2019). The influence of an engineering design experience on elementary teachers' nature of engineering views. *International Journal of Technology and Design Education* 1-22.

Kaya, E., Deniz, H., & **Yesilyurt, E.** (accepted). Teaching engineering with mechanical engineering design challenge. *Science Scope.*

Kaya, E., Newley, A., **Yesilyurt, E.,** & Deniz, H. (in press). Teaching computational thinking to pre-service elementary science teachers and measuring self-efficacy beliefs. *Journal of College Science Teaching*

Kaya, E., Newley, A., Deniz, H., **Yesilyurt, E**., & Newley, P. (in press). Improving views of the nature of engineering through LEGO Mindstorms EV3 Educational Robotics. *Journal of College Science Teaching.*

Kaya, E., Yesilyurt, E., Newley, A., & Deniz, H. (2019). Examining the impact of a computational thinking intervention on pre-service elementary science teachers' computational thinking teaching efficacy beliefs, interest and confidence. *Journal of Computers in Mathematics and Science Teaching*, *38*(4), 385-392.

Deniz, H., Kaya, E., & **Yesilyurt, E**. (2018). Exposing elementary students to engineering design process through soda can crusher design challenge. Science & Children.

Newley, A., Kaya, E., Deniz, H., & **Yesilyurt, E. (**2018). Celebrity statues: Learning computational thinking by designing biomimetic robots. *Science Scope*, *42*(1), 74.

Deniz, H., Kaya, E., & **Yesilyurt, E**. (2018). Engineering Encounters. *Science and Children*, *56*(2), 74-78.

Kaya, E., Newley, A., Deniz, H., **Yesilyurt, E.,** & Newley, P. (2017). Introducing engineering design to a science teaching methods course through educational robotics and exploring changes in views of preservice elementary teachers. *Journal of College Science Teaching*, *47*(2).

Newley, A., Deniz, H., Kaya, E., & **Yesilyurt, E.** (2016). Engaging elementary and middle school students in robotics through hummingbird kit with snap! visual programming language. *Journal of Learning and Teaching in Digital Age*, 1(2), 20-26.

Kaya, E., Deniz, H., Newley, A., **Yesilyurt, E.,** & Khalilov, F. (2016). Preparing Ugandan secondary teachers for robotics and technology competitions. *Journal of Learning and Teaching in Digital Age*, 1(1), 12-17.

Sen, M. & **Yesilyurt, E.** (2014). The development of the Paranormal Belief Scale (PBS) for science education in the context of Turkey. *International Journal of Education in Mathematics, Science and Technology*, *2*(2), 107-115.

Manuscripts Under Review

Yesilyurt, E., Deniz, H., & Kaya, E. Development and validation of an engineering teaching efficacy beliefs instrument. Journal of Engineering Education.

Yesilyurt, E., Deniz, H., & Kaya, E. (under review). Sources of engineering self-efficacy for pre-service teachers. Journal of Engineering Education.

Kaya, E., Deniz, H., **Yesilyurt, E**. (under review). Integrating 3d printing with mechanical trash grabber design challenge. Science Scope.

Marti, E., Kaya, E., **Yesilyurt, E** & Deniz, H. (under review). High school science teachers' views of nature of engineering through sustainable engineering design. Journal of Science Education and Technology.

Developing Manuscripts to be Submitted to Refereed Journals

Deniz, H., **Yesilyurt, E**., & Kaya, E. (in preparation). The influence of an authentic engineering design experience on elementary teachers' engineering teaching efficacy beliefs.

Yesilyurt, E. & Turgut, R. (in preparation) General education pre-service teachers' attitudes, and beliefs/knowledge regarding second language acquisition and English language learners.

Yesilyurt, E.& Raeisi, M. & Deniz, H. (in preparation). Development and validation of pre-service teachers' approaches to teaching evolutionary theory scale.

Yesilyurt, E. (in preparation). Pre-service elementary teachers' beliefs about science teaching and learning.

Conference Proceedings

Yesilyurt, E., Deniz, H. & Kaya, E. (2020, Apr 17 - 21) *Sources of Self-Efficacy in an Engineering Professional Development Program for In-Service Teachers* [Paper Session]. AERA Annual Meeting San Francisco, CA http://tinyurl.com/tht6tw8 (Conference Canceled)

Yesilyurt, E. (2020, Apr 17 - 21) *Examining Preservice Teachers' Beliefs About Teaching and Learning Science* [Roundtable Session]. AERA Annual Meeting San Francisco, CA http://tinyurl.com/tbal2b2 (Conference Canceled)

Yesilyurt, E. (2020, March). *History of engineering and engineering education*. The paper presented in the Sandra K. Abell Symposium at the annual meeting of the National Association for Research in Science Teaching (NARST). Portland, OR. (Conference Canceled)

Yesilyurt, E. (2020, March). *Examining elementary students' images of engineers and interests in engineering careers*. The paper presented in the Basu Scholars Symposium at the annual meeting of the National Association for Research in Science Teaching (NARST). Portland, OR. (Conference Canceled).

Deniz, H., **Yesilyurt, E.** & Kaya, E. (2020, Apr 17 - 21) *Toward Defining Nature of Engineering in the Next Generation Science Standards Era* [Poster Session]. AERA Annual Meeting San Francisco, CA http://tinyurl.com/whny5tb (Conference Canceled)

Deniz, H. **Yesilyurt, E.,** Kaya, E., Newly, A. & Lin E. (2020, April). Integrating engineering, science, reading, and robotics across grades 3-8 in a stem education era. The paper presented at the annual meeting of the Society for Information Technology & Teacher Education International Conference. (Online)

Deniz, H. **Yesilyurt, E.,** & Kaya, E. (2020, March). *Engineering Professional Development with Robotics and Assessment of K-12 Teachers' Understandings of Nature of Engineering*. The paper is accepted to present at the annual meeting of the National Association for Research in Science Teaching (NARST). Portland, OR. (Online).

Liu, K., Arroyo, M., Preston, B. & **Yesilyurt, E.** (2020, February). *Using critical counter-narrative to prepare teacher educators of color to teach about race and equity*. The paper presented at the annual meeting of the Association of Teacher Educators, Atlantic City, NJ.

Wilhelm J., Cole, M., Driessen, E., **Yesilyurt, E.**,….(2019, November). *Spatial-scientific snapshots of middle-level students' lunar understanding.* Paper presented at the 2019 Annual Convention of the School Science and Mathematics Association Salt Lake City, Utah.

Yesilyurt, E., & Raeisi, M. (2019, April). *Exploring the factors related to pre-service teachers' approaches to teaching evolution*. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST). Baltimore, MD.

Yesilyurt, E., Deniz H., & Kaya E. (2019, April). *Sources of engineering teaching self-efficacy for pre-service elementary teachers*. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST). Baltimore, MD.

Yesilyurt, E., Deniz H., & Kaya E. (2019, April). *Development and validation of the engineering teaching efficacy belief instrument.* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST). Baltimore, MD.

Yesilyurt, E., & Raeisi, M. (2019). *Examining pre-service teachers' perceived approaches to teaching evolution*. Global Conference on Education and Research *(GLOCER 2019)* USA.

Yesilyurt, E., Deniz H., & Kaya E. (2019, January). *Improving upper elementary students' nature of engineering views with an engineering design ex*perience. Paper presented at the annual meeting of the Association for Science Teacher Education (ASTE). Savannah, Georgia.

Kaya E., **Yesilyurt, E.,** & Deniz H. (2019, April). *Assessing the impact of a computational thinking intervention on k-12 science teachers' robotics teaching efficacy beliefs, interest and knowledge in educational robotics.* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST). Baltimore, MD.

Kaya, E., Deniz, H., **Yesilyurt, E.,** & Newley, A. (2019, March). *examining the impact of a computational thinking intervention on pre-service elementary science teachers' computational thinking teaching efficacy beliefs, interest and confidence*. The Society for Information Technology and Teacher Education. Las Vegas, NV, USA.

Kaya, E., **Yesilyurt, E**., Newley, A. D., & Deniz, H. (2018, June), *Investigating computational thinking self-efficacy beliefs of pre-service elementary teachers* Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. https://peer.asee.org/30721

Newley, A., & Kaya, E., & Deniz, H., & **Yesilyurt, E.** (2018, June), *Teaching K-8 Students engineering design process through zoombinis* Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. https://peer.asee.org/31055

Marti, E. J., & Kaya, E., & Deniz, H., & **Yesilyurt, E.,** & Iglesias, J. (2018, June), *Assessing high school science teachers' nature of engineering (NOE) perceptions with an open-ended NOE instrument (Fundamental)* Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah. https://peer.asee.org/29821

Yesilyurt, E., & Deniz H. (2018, April). *Investigating science teachers' causal schemas in the context of evolutionary theory.* Paper presented at the annual meeting of the American Educational Research Association (AERA). New York, NY.

Deniz, H., Kaya, E., & **Yesilyurt, E.** (2018, April). *The differential impact of two engineering professional development programs on elementary teachers' engineering teaching efficacy beliefs.* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST). Atlanta, Georgia.

Kaya, E., Deniz, H., & **Yesilyurt, E.** (2018, January*). Examining the impact of a relatively short intervention on science teachers' robotics teaching efficacy beliefs and interest in educational robotics.* Paper presented at the annual meeting of the Association for Science Teacher Education (ASTE). Baltimore, MD.

Yesilyurt, E., &Liu, K. (2018, February). *Single-Case study: Critical storytelling in a doctoral teacher education course*. Paper presented at the annual meeting of the Conference on Academic Research in Education (CARE). Las Vegas, NV.

Yesilyurt, E., & Turgut, R. (2018, February). *Investigating pre-service teachers' knowledge, attitudes and beliefs about second language acquisition and english language learners.* Paper presented at the annual meeting of the American Association of Behavioral & Social Science Conference (AABSS). Las Vegas, NV.

Kaya, E., Newley, A. D., Deniz, H., & **Yesilyurt, E.** (2017, June), Board # 115: EEGRC Poster: *Improving pre-service elementary teachers' nature of engineering views with the use of ev3 robotics.* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/27698

Marti, E. J., Deniz, H., Kaya, E., & **Yesilyurt, E.** (2017, June), *Board # 98: High school science teachers' views of nature of engineering and application of engineering design practices.* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/27967

Newley, A. D., Kaya, E., & **Yesilyurt, E.,** & Deniz, H. (2017, June), *Board # 104: Measuring engineering perceptions of fifth-grade minority students with the draw-an-engineer-test (DAET)* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/27675

Yesilyurt, E., Turgut, R., & Kaya, E. (2017, April). *General education preservice teachers' attitudes, and beliefs/knowledge regarding second language acquisition and English language learners*. Paper presented at the annual meeting of American Educational Research Association (AERA). San Antonio, TX.

Deniz, H., **Yesilyurt, E.,** Kaya, E. & Trabia, M. (2017, April). *The Influence of an authentic engineering design experience on elementary teachers' engineering teaching efficacy beliefs.* Paper presented at the annual meeting of National Association for Research in Science Teaching (NARST). San Antonio, TX.

Deniz, H., **Yesilyurt, E.,** Kaya, E. & Trabia, M. (2017, April). *The Influence of an authentic engineering design experience on elementary teachers' nature of engineering views.* Paper presented at the annual meeting of National Association for Research in Science Teaching (NARST). San Antonio, TX.

Yesilyurt, E, Cakiroglu J. & Oztekin, C. (2015, April). *Conceptual, structural and epistemic aspects of argumentation practices within the evolutionary context.* Paper presented at the annual meeting of the National Association for the National Association for Research in Science Teaching (NARST). Chicago, IL.

Aydin, G. Ç., Evren, E., Atakan, İ., Sen, M., Yilmaz, B., Pirgon, E., **Yesilyurt E.** ... & Ebren, E. (2016, January). *Delphi technique as a graduate course activity: Elementary science teachers' TPACK competencies*. Paper presented at the *SHS Web of Conferences* (Vol. 26). EDP Sciences.

Workshops

Deniz, H., **Yesilyurt, E.,** & Kaya, E. (2019, November) Integrating Engineering and Computational Thinking with 3D-Printed Engineering Design. The 2019 Annual Convention of the School Science and Mathematics Association (To appear). Salt Lake City, Utah.

Deniz, H., **Yesilyurt, E.,** & Kaya, E. (2019, March). *Integrating 3D Design and Printing with Mechanical Trash Grabber Design Challenge within the Context of the Next Generation Science Standards*. The Society for Information Technology and Teacher Education. Las Vegas, NV. (To appear).

Deniz, H., Kaya, E., & **Yesilyurt, E.** (2018, October). Integrating Engineering Design with Science and Language Arts. National Science Teachers Association (NSTA) 2018 Conference. Reno, NV.

Deniz, H., Kaya, E., & **Yesilyurt, E.** (2018, January). Integrating Engineering Design with Science and Language Arts within the Context of the Next Generation Science Standards. 2018 Association for Science Teacher Education (ASTE). Baltimore, MD.

Mini-Grant Proposals

Grant Title: UNLV Assessment Mini-Grant (Fall, 2019)
PI: Responsibilities included leading the research, develop the course curriculum, writing practitioner and/or research-oriented manuscripts and overall research administration

Institute: Office of the Executive Vice President and Provost
RFA Topic: Towards a Meaningful Assessment of Learners' Understanding About Nature of Engineering - Nature of Engineering Instrument (NOEI)
Requested Amount: $2738 (in review)

Grant Title: UNLV Scholarship of Teaching and Learning Grant (2017)

Co-PI: Responsibilities included assisting with the research, writing practitioner and/or research-oriented manuscripts and overall program administration

Institute: Office of the Executive Vice President and Provost
RFA Topic: Introducing Engineering to Elementary Pre-service Teachers through 3D Printing and Educational Robotics
Received Amount: $2738

Grant Title: Center for Math, Science, and Engineering Education (2016)
Co-PI: Responsibilities included assisting with the research, writing practitioner and/or research-oriented manuscripts and overall program administration

Institute: UNLV
RFA Topic: Introducing Engineering to Elementary Pre-service Teachers through Educational Robotics
Received Amount: $2000

Services

2020-Present	CBE--Life Sciences Education Editorial Board Member
2019-Present	Journal of Science Teacher Education (JSTE) Editorial Board Member
2019-Present	Graduate Student Volunteer in the NARST Research Committee
2017-Present	American Educational Research Association (AERA) reviewer for Division C (Science) and Division K (Teaching & Teacher Education)
2017-Present	National Association for Research in Science Teaching (NARST) reviewer for Strand 1 (Science Learning, Understanding and Conceptual Change,), 7 (Pre service Science Teacher Education and Strand) and 13 (History, Philosophy, Sociology, and Nature of Science)
2018-Present	Association for Science Teacher Education (ASTE) reviewer for strand pre-service science teacher preparation
2017-Present	American Society for Engineering Education (ASEE) Reviewer for strand: pre college engineering education
2017-2018	AERA Division K campus liaison at UNLV (2017-2018). Responsibilities include organizing meetings to inform master and Ph.D. students about AERA conferences.
2016- Present	Science Fair Judge at Coral Academy of Science Las Vegas: CASLV

Professional Skills

- **Languages:** Turkish (Native), English (Fluent),
- **Computer Skills*:*** SPSS (Advanced), AMOS(Advanced), R(Intermediate), Mplus (Intermediate), Lisrel (Intermediate), Pajek (Intermediate), MS Office Suite (Expert), C# (Intermediate), JAVA (Intermediate), MATLAB (Intermediate), AutoCAD (Intermediate), HTML, CSS, JavaScript (Intermediate), Photoshop (Intermediate), LiveCode (Intermediate)

Professional Memberships

- National Science Teachers Association (NSTA)
- American Society of Engineering Education (ASEE)
- National Association for Research in Science Teaching (NARST)
- American Educational Research Association (AERA)
- Association for Science Teacher Education (ASTE)
- International Technology and Engineering Educators Association (ITEEA)