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PROJECT-BASED SERVICE-LEARNING AS LOGO-PEDAGOGY: TEACHING FOR EXISTENTIAL PURPOSE IN PRE-COLLEGE ENGINEERING EDUCATION

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PROJECT-BASED SERVICE-LEARNING AS LOGO-PEDAGOGY: TEACHING FOR EXISTENTIAL PURPOSE IN PRE-COLLEGE ENGINEERING EDUCATION

by

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Dedication

For my first students of St. John Eudes Elementary School in California who forever changed my life and inspired me. And, for my sweet nieces, Laylah and Mila, who have all changed my life and given me a deeper sense of meaning in life. And, to my Lord and my God, in whom lies my ultimate purpose.

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"Therefore, I tell you, do not worry about your life, what you will eat or drink, or about your body, what you will wear. . . . But seek first the kingdom of God and his righteousness, and all these things will be given you besides."

—Matthew 6:25-34

Abstract

Project-Based Service-Learning as Logo-Pedagogy: Teaching for Existential Purpose in Pre-College Engineering Education

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The imperative for bolstering engineering education at the precollege level is usually framed within the context of improving U.S. global competitiveness but this potentially cheapens the inherent value of an engineering education and obfuscates the potentially socially purposeful aspects of engineering. Drawing from design-based research, this case study examines how a project-based service-learning (PBSL) engineering design unit contributed to students' sense of purpose in life and perceptions of engineering. It takes an ecological approach in that it considers the perspectives of students, the teacher, professional engineering mentors to understand and outline guiding principles for PBSL engineering experiences at the pre-college level.

Student perspectives on the PBSL unit centered around six themes: *impact of the unit*; *affect*; *meaningfulness*; *learning*; *teamwork/collaboration*; and, *agency*. Three themes characterized student reflections on purpose in life: *notions of purpose in life*; *student purposefulness*; *career aspirations*. Students also discussed engineering along two broader

themes of their: *engineering notions* and *engineering interests*. The educators' (teacher and mentors) perspectives on *teaching priorities and strategies* for the unit aligned along seven themes: *exposure*; *messages about engineering*; *hands-on/physical experience*; *encouraging student ideas*; *room for mistakes and failure*; *teamwork*; and *involving expert engineers*. They identified at least *six positive aspects of the unit*: *exposure; engineering design process and habits-of-mind; authenticity; motivation and purposefulness; student ideas; and student accomplishment*. Conversely, they also discussed at least four primary areas of improvement: *facilitating teamwork; adhering to design specifications and constraints; involving expert engineers throughout the process; and timing*.

Overall, the findings suggest that student participation in PBSL engineering units can contribute to their purpose development by facilitating opportunities for socially purposeful engagement within a STEM context. Furthermore, PBSL engineering units concretize the socially purposeful aspects of engineering, subverting wider public perceptions of engineering as a socially-unconcerned profession. Future PBSL engineering units at the pre-college level should emphasize: student input, ideas, and hands-on engagement; process over outcome, especially the engineering design process; involving the community; and, reflection.

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CHAPTER ONE:
INTRODUCTION

> How can we expect that young people will find meaning in what they are doing if we so rarely draw their attention to the personal meaning and purpose of what we work at in our daily lives?
>
> -*William Damon, The Path to Purpose, 2008*

Introduction

In 2007, an unassuming, young Malawian teen, William Kamkwamba, stood on a TEDGlobal stage in Tanzania and captivated his audience as he nervously explained how, five years previously, his humble design of a windmill made from junkyard parts and blue gum trees had brought electricity to his family's hut. Although forced to forsake his schooling due to poverty exasperated by a severe famine that had devastated his village of Wimbe in the early 2000s, his sheer determination, curiosity, and concern for his community led the resourceful 14-year-old to teach himself English in order to learn the principles of thermodynamics and windmill design from tattered copies of science textbooks found in Wimbe's modest library (TED, 2007). His ingenuity eventually saved his village from starvation and devastation, as he later constructed more windmills to power an irrigation system for his community's predominantly agrarian society (Kamkwamba & Mealer, 2010). Kamkwamba went on to obtain an environmental studies degree with a minor in engineering from the prestigious Dartmouth College and subsequently established himself as a global leader in human-centered design, serving underserved communities across Africa, Asia, and the Americas (Moving Windmills Project, 2013). While his story does not end there, this snippet of Kamkwamba's accomplishments is a testament to the power of perseverance and perhaps even purposefulness when they are coupled with endeavors in science and engineering. A perusal of Google's Science Fair website also illustrates this potential, introducing a number of similarly remarkable youth across the globe who are solving pressing and complex problems, such as water pollution and cancer detection, within their communities (Google, 2019). Of course, there is no shortage of equally talented and inspiring young minds here in the United States.

Stories like Kamkwamba's and others like him, though, ought to give us pause and question the prevalent rhetoric around STEM (science, technology, engineering, math) education reform in the United States. For at least the past two decades, the urgency for STEM education reform has often been couched within a rhetoric of fortifying an American workforce prepared and competitive enough to meet the demands of the 21st-century global economy (Achieve Inc., 2010; Borrego & Bernhard, 2011; Suter & Camilli, 2019; NRC, 2012). This rhetoric usually stems from concerns over metrics that show Americans still trailing their European and Asian counterparts in STEM engagement and participation, even if these metrics have shown steady improvement over the past decade or so (National Science Board, 2018; OECD, 2019). However, this narrative and the anxiety of "trailing behind" appears to be distinctively American when contrasted with European narratives, which seem to position STEM education reform as a necessity to bolster career mobility and to improve the global economy as a whole (Borrego & Bernhard, 2011).

Yet, while American imperatives to bolster its own workforce may be important and worthwhile in their own right, this emphasis on competitive workforce preparation not only cheapens the inherent value of a quality STEM education with its implicitly utilitarian argument for education reform, but it may also obscure other worthwhile motivations for and areas of need in STEM education reform. Perhaps one such impetus, oft ignored (if not altogether absent) in the STEM education literature, is the cultivation of students' sense of self-actualization and "eudaimonic well-being," or, "the knowledge of what makes one's life meaningful and what maximizes one's potential" (Yeager & Bundick, 2009, p. 425). Past psychology research and motivation theories have shown that a sense of personal meaningfulness, and purposefulness especially as it pertains to student interests and goals, is a crucial aspect of the optimal conditions for learning and overall well-being in youth (Ford & Smith, 2007; McCombs, 1991; Maton, 1990; Pizzalato et al., 2011). Furthermore, other research has found that there are strong links between altruism and purpose development (Bronk, 2014) and that altruism, or social-purposefulness, is a "meta-amplifier" that "transcends the impact of other motivational amplifiers" (Ford & Smith, 2007, p. 164) and correlates to positive outcomes in all domains of human well-being, including learning.

Research Questions

In light of the calls from the engineering community (National Academy of Engineering [NAE], 2017; Riley & Lambrinidou, 2015) to dispel images of engineering as a socially-unconcerned discipline, this dissertation aims to explore pedagogical strategies which may help repurpose K-12 STEM, specifically engineering education, toward fostering student well-being. It is thus predicated on the argument that one primary goal of pre-college engineering education ought to be fostering a sense of purpose, especially social purposefulness, among students. More specifically, this research draws on motivation theories from psychology and educational psychology literature and seeks to examine how socially-oriented pedagogies such as project-based service-learning in pre-college engineering education can potentially promote students' sense of purpose in life and their understanding of engineering, as well as their interests and career aspirations in engineering. Underscoring the exploration in this research is a dual interest in exploring the development of youth's purpose and youth STEM career interest and aspirations within a middle school, project-based service-learning (PBSL) context. In so doing, the research adopts a broader ecological approach to a view of learning, in that it also considers the perspectives of the teacher and that of professional engineering mentors from the students' community. It is thus motivated and framed by the following three research questions:

1. How, if at all, does participation in a K–12 PBSL engineering design unit contribute to middle school students' sense of purpose in life and their perceptions of and interests or aspirations in engineering?
2. What features and instructional priorities did the educators (teachers and mentors) perceive as being important to facilitating a K–12 PBSL engineering design unit, especially with regard to promoting youth purpose and interest in engineering?
3. What are some initial guiding principles for the design and enactment of K–12 PBSL engineering design units?

To explore these three research questions, this research assumed a design-based research approach within the context of a case study of one sixth-grade class's experience of participating in a PBSL engineering design challenge. To explore the first research question, I conducted semi-structured interviews to elicit the students' perspectives on how such a learning experience potentially influenced their sense of purpose in life and their engineering career interests. Survey data and artifacts of student work from the unit also inform the findings with respect to the first question. Much like the first research question, examining the second research question entailed semi-structured interviews with participating teachers and engineering mentors to better understand their perspectives as to what features and messaging they saw as being important within an engineering PBSL unit. Finally, to answer the third research question, I synthesized the student and educator perspectives along with my own reflections in collaborating on the development and implementation of the PBSL engineering unit at the center of this research. Overall, by assuming a largely qualitative and ecological approach, this research aims to provide a richer understanding of whether PBSL in precollege engineering education can be a context that fosters students' sense of purpose in life and encourages their interests and aspirations in engineering and, if so, which curriculum and pedagogical features of PBSL engineering units may facilitate these outcomes.

Need for the Study

In his 2008 book, *The Path to Purpose: How Young People Find Their Calling in Life*, William Damon, a preeminent scholar of adolescent psychology, chronicled his findings and reflected on youth purposelessness in life, which appeared to him to be the chief threat to youth's ability to thrive (the focus of his research for nearly three decades). In a chapter entitled, "Young Lives Adrift," Damon (2008) elucidates the existence of an alarming and increasing trend among American youth, who seem to be suffering from a sense of disillusionment and disengagement in life. In the following excerpt, Damon (2008) captures the essence of this existential deficit, which seems to afflict American youth, even in spite of all the seeming material advantages of a developed nation:

> From a distance, considering the terrible conditions that people find themselves in around the world, it may be hard to see what these privileged youth find lacking in their lives. Yet something is certainly missing. In the past, some educators have called this element "motivation," and I agree that sufficient motivation is indeed lacking. But, I would also argue that the core problem is the lack of a *source* of motivation, the lack of a sense of purpose. In the long run, the lack of purpose can destroy the foundations of a happy and fulfilled life. (p. 16)

Indeed, extensive psychological research and theoretical exposition corroborate Damon's assertion here. Past adolescent psychology literature suggests that having a sense of purpose in life is fundamental to positive adolescent development (Bronk 2011; Damon, 2008; Yeager & Bundick, 2009) and human flourishing more broadly (Damon 2008; Ford & Smith, 2007; Frankl, 2006).

Yet, the pervasive lack of a sense of purpose in life among young people should be cause for concern. Damon (2008) found that nearly 85% of the adolescents and young adults he and his team surveyed and interviewed either expressed no clear purpose for their lives (about 25%) or only ambiguous ones at best (nearly 60%). Moran (2009; 2010) similarly found that out of a sample of 270 American youth (from sixth-grade through college), only 25% appeared to have a well-developed sense of purpose in life, while 40% seemed to have no sense of purpose in life. An underdeveloped sense of purpose in life can have profound negative implications in a young person's life (Damon, 2008), not the least of which could include adverse effects on their learning. For example, in a series of studies of over 2,000 adolescents, Yeager et al. (2014) found that students who lacked a strong sense of purpose in life were less likely to persist and exhibit academic self-regulation behaviors, whereas a more developed sense of purpose predicted greater academic persistence and self-regulation, even when academic tasks seemed boring. On the other hand, Yeager and his colleagues (2014) found that even brief guided reflections on one's purpose in life and in learning improved high school students' STEM grade point averages (GPA) and had a particularly high impact on underachieving students, who showed the most growth post-intervention. It is interesting, then, to consider what the potential implications of such findings might be in light of trends elucidating student views on STEM disciplines.

Results reported in the 2015 *Nation's Report Card*, a summary of the *National Assessment for Educational Progress* (NAEP) test, indicate that middle and high school students hold somewhat modest views on mathematics and science. While American adolescents appear to have mostly favorable views of math, with more than 40% of eighth and twelfth graders reporting high views on it, student views on science appear to be far less positive (NCES, 2015). Only 28% of the nation's eighth graders and 29% of the nation's 12^{th}-graders had a highly positive view of science, while 52% and 46%, respectively, held a moderate view of science, and nearly a quarter of both eighth and 12^{th}-graders had a negative (low) view of science (NCES, 2015).

Adolescents' views on engineering did not necessarily fare much better. Polling data from The National Academy of Engineering (NAE) (2008, 2017) found that while both American teens and adults associated engineering with proficiency in mathematics and scientific understanding, they largely did not view engineering as a profession that had an inherently positive impact on the world nor as one that was concerned with society's problems. Indeed, in 2003, less than 40% of participants (including adults and teens) perceived engineers as professionals who either care about the community (37%), are sensitive to societal concerns (28%), or save lives (14%) (NAE, 2008). Similarly, in 2006, the NAE (2008) found that only 36% of teens viewed engineers as having a positive effect in the world and a mere 22% saw engineers as leaders in society. Thus, with nearly 75% of American youth reporting negative or only moderately positive views of science at best, it seems that many young people are unaware of the many positive attributes of engineering, especially as a socially-purposeful profession. It appears, then, that American youth are not particularly interested in the STEM disciplines. At the very least, these figures suggest that there is yet more to be done to engage students in STEM learning that better showcases not only the vast contributions made possible by the STEM disciplines, but also the inherent value they possess, especially as it pertains to engineering.

The engineering community has also made efforts to emphasize the prosocial nature of engineering. For example, the NAE's *Changing the Conversation* campaign espouses messages about engineering that demonstrate that "engineers make a world of difference" and that "engineering is essential to our health, happiness, and safety," along with two other similar themes (National Academies of Sciences, Engineering, Medicine, 2017). The crux of these messages highlights the profound societal impacts spurred by engineering innovations in virtually all manner of human endeavor and most especially in computing, medicine, geopolitics, environmental preservation, and space exploration (NAE, 2017). Similarly, Riley and Lambrinidou (2015) proposed that the engineering community aspire to incorporate a more prominent vision of social justice into its identity in an effort to increase the sense of social responsibility and consciousness within the profession. They accordingly propose a canon for this aspirational vision for engineering with values that center around service, social justice, cultural and epistemic humility, dignity and worth of the person, importance of human relationships, and peace.

This recent consciousness to reframe the image of engineering suggests that there is an underlying understanding that engineering is germane to a thriving and civil society. As the education community continues to recognize the importance of understanding early engineering experiences and how best to foster them, this message should thus be emphasized in engineering education efforts, especially in the precollege years, when students begin forming ideas of their future “possible selves” (Markus & Nurius, 1986). It behooves STEM educators, then, to demonstrate, in authentic and meaningful ways, that engineering, at its best, can be a profound social good and that engineers can be agents of such good in society. It is therefore worthwhile to examine the contexts and pedagogies that might best lend themselves to these aims.

Significance of the Study

Although interest and research on youth purposefulness and the role of schools in its development have been steadily growing over the past decade, these efforts appear to primarily concentrate on fostering youth purposefulness in the broader academic setting. There are far fewer discussions, however, that center on the development of youth purposefulness within specific disciplinary contexts, such as those of the STEM disciplines, and even less so within the specific context of engineering education. With this in mind, the present research aims to examine the development of youth purpose in precollege engineering education contexts, as well as the relationship of youth purpose to youth interest and career aspirations in engineering. This thesis thus seeks to intersect research on youth purposefulness with those efforts in STEM/engineering education research that aim to understand the best pedagogical approaches for teaching pre-college engineering and promoting motivation for STEM learning.

To better explain the foundations and design of this research, the ensuing chapter, Chapter 2, first provides a comprehensive literature review, recounting the salient theoretical frameworks and past findings in the relevant extant literature on youth purposefulness, service learning, and pre-college engineering education. Chapter 3 then extensively details the methods of the study, including the sequence and key learning activities of the PBSL engineering design unit at the center of this research. Chapters 4 and 5 present the findings on the student and educator perspectives, respectively, and particularly as they relate to the first and second research questions. Chapter 6 then offers a discussion of these findings, including a synthesis of these findings to answer the third research question. It also discusses the limitations of this study and the future directions of research for which this present thesis may serve as a foundation.

CHAPTER TWO:
LITERATURE REVIEW

This research lies at the convergence of at least three broader fields of education research: curriculum and instruction, educational psychology, and engineering education. More specifically, this research draws on the theories and past evidences pertaining to service-learning as a pedagogy, purpose as a motivational construct in learning, and the qualities of effective pre-college engineering education. This literature thus informs the theoretical framework on which this research is built. As such, in the pages that follow, I first review the literature that operationalizes service-learning and purpose. I then explain how purpose is integral to youth thriving and academic success, drawing upon Motivational Systems Theory (MST) (Ford, 1992). Additionally, I draw on Markus and Nurius' (1986) Possible Selves Theory as a framework to understand student career aspirations. Next, I explore the literature that theorizes which pedagogies may be optimal for fostering youth purpose. The chapter then turns to the engineering education literature to better understand what scholars in the field have identified as the goals and necessary facets for quality pre-college engineering education. Finally, the chapter concludes with a brief review of the empirical research that elucidates the learning and academic outcomes resulting from project-based service-learning in engineering contexts at both the pre-college and undergraduate levels.

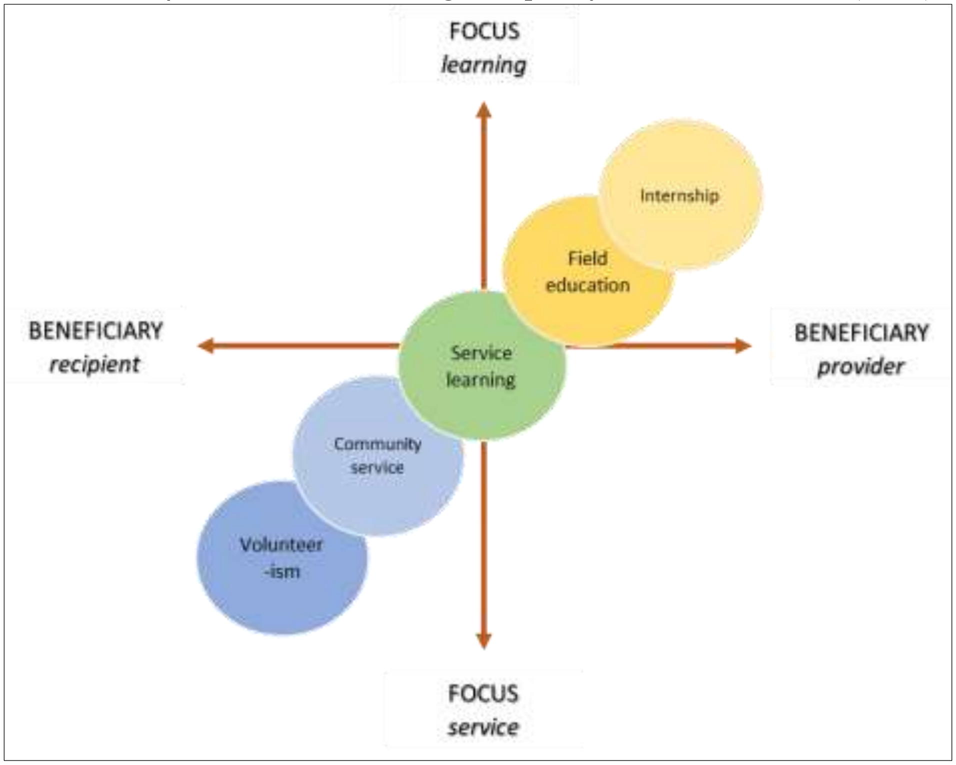
What is Service-Learning?

The notions of democratic education and students being the constructors of their knowledge are not only intimately tied to each other but also have significant implications for the service-learning pedagogy. Dating back to the 19th century, service-learning pedagogy has enjoyed multiple waves of embrace within the American education system (Bielefeldt & Pearce, 2012; Swanson et al., 2014). Though not new, there still exists some ambiguity to its definition.

Nevertheless, there are some consistent characteristics which seem to emerge out of a synthesis of the service-learning literature and which distill the essence of the pedagogy more clearly. Chief among these is that service-learning is predicated on a notion of mutual beneficence. That is, the serving learners benefit from engaging in a rich, meaningful learning experience while the served community partners gain from the service provided by the students participating in the service-learning project (Swanson et al., 2014). Swanson et al. (2014) offered a helpful representation of this when they located service-learning along two axes: beneficiary, with a spectrum of community versus student, and focus, which ranges between service and learning. (See Figure 2.1 below.)

Figure 2.1

Continuum of Service and Learning. Adapted from Swanson et al. (2014)



In addition to this descriptor of service learning, Pritchard and Whitehead (2004) also outlined four fundamental facets of service learning:

- Students provide service to meet authentic needs.
- Service links through deliberate planning to the subject matter students are studying and the skills and knowledge they are developing in school.
- Students reflect on the service they provide.
- Service-learning is coordinated in collaboration with the community. (p. 3)

Other scholars of service-learning research have suggested additional essential components of service-learning. For example, several have suggested that ongoing reflection on the service-learning experience and its pertinence to the academic objectives of the curriculum is an essential part of service-learning (Bielefeldt & Pearce, 2012; Bringle & Hatcher, 2009; Claus & Ogden, 1999; Madden, 2000). At its essence, however, the distinguishing feature of service-learning from other, similar pedagogies is the bidirectional advantage that should result from a service-learning experience. Not only should the learners partaking in the service-learning curriculum acquire a rich educational experience, but the community partners involved should also benefit from the service provided by the learners (Swanson et al., 2014). As these characterizations of service-learning might suggest, service-learning is intended to be a meaningful and immersive learning experience that is authentically situated to meet the real needs of a student's community. As such, service-learning is inherently deeply tied to sociocultural and constructivist learning theories, and it is thus worth briefly examining some of these underpinnings.

Service-Learning and Sociocultural Constructivist Learning Theories

The service-learning pedagogy is intimately linked to the seminal sociocultural and constructivist theories of key educational philosophy figures like Jean Piaget, Lev Vygotsky, and John Dewey. While the reader is directed toward the wealth of past literature (Payne, 2000; Pizzolato et al., 2011) for a more thorough treatment of the underlying learning theories and philosophies of service-learning, Pritchard and Whitehead (2004) succinctly elucidate this relationship:

> The connections between these propositions from constructivist learning theory and service-learning are readily apparent. Service-learning engages students in interacting with the world and thus helps them build new cognitive structures in accord with Piaget's general view of intellectual development. It involves students in collaborative work with teachers, peers and community members and thus engages them in the dialogic social interaction identified by Vygotsky as crucial to intellectual maturation. (p. 7)

By its very nature then, the service-learning philosophy inherently values the notion that students are active agents and constructors of their knowledge in the fact that service-learning seeks to immerse students in and situate their learning in an authentic, sociocultural context. In doing so, students are encouraged to construct knowledge with others, peers and community partners alike. These sociocultural and constructivist underpinnings of service learning thus suggest that this pedagogy rests on a theoretical foundation that positions it to be an optimal context for learning that fosters the development of youth purpose.

Purpose and Meaning as Psychological Constructs

Before examining how these underlying principles of service-learning may potentially contribute to the development of youth purpose, it is necessary to first understand the construct of existential purpose, as defined by the literature on psychology.

Purpose

The interest in *purpose-in-life* (often shortened to *purpose)* as a psychological construct and facet of human development directly stems from the widely influential work of the renowned Viennese psychiatrist and Holocaust survivor Viktor Frankl (Damon, 2008; Yuen et al., 2017). In his seminal book, *Man's Search for Meaning*, Frankl recounts his experiences and observations during his time in Nazi concentration camps; these combined with his clinical experience led him to put forward his theory of "logotherapy," the crux of which lies in his assertion that a "*will to* *meaning"* is fundamental to human flourishing and well-being (Bronk, 2014; Damon, 2008; Frankl, 1959/2006; Yuen et al., 2017), which includes the ability to cope with and overcome "unavoidable suffering" (Frankl, 1959/2006, p.111). Frankl has since been acclaimed as the father of the third school of Viennese psychology (after Sigmund Freud and Alfred Adler), while logotherapy and its related constructs have also been the focuses of much empirical research in psychology (Bronk, 2014; Thir & Batthyány, 2016).

Although Frankl, as well as earlier works in this line of inquiry, either did not necessarily distinguish between *meaning* and *purpose* in life or have offered several varying (and sometimes confounding) conceptions of these constructs (Bronk, 2014; Damon, Menon & Bronk, 2003; Yuen et al., 2017; Yeager & Bundick, 2009), more recent research from developmental and social psychology has defined and nuanced these constructs more specifically (Bronk, 2014; Damon, Menon & Bronk, 2003). Bronk (2014) identified three salient features that underscored the prevalent theoretical or empirical facets of purpose in the extant literature on purpose and meaning: "commitment, goal-directedness, and personal meaningfulness" (p. 4). These three features derive from Damon, Menon, and Bronk's (2003) conception of purpose, which is perhaps the most commonly accepted definition of purpose. In their synthesis of the prior literature, along with their own empirical investigations on purpose, Damon, Menon, and Bronk (2003) set out to more explicitly and distinctly operationalize purpose as follows:

> *Purpose is a stable and generalized intention to accomplish something that is at the same time meaningful to the self and consequential for the world beyond the self* [emphasis added]. We choose this definition because it highlights the following points:
>
> 1. Purpose is a goal of sorts, but it is more stable and far reaching than low-level goals such as "to get to the movie on time," . . .
> 2. Purpose is a part of one's personal search for meaning, but it also has an external component, the desire to make a difference in the world, to contribute to matters larger than the self.

3. Unlike meaning alone (which may or may not be oriented towards a defined end), purpose is always directed at an accomplishment towards which one can make progress. (p. 121)

Elsewhere, Damon further elaborated on this conception, when he described *life purpose*, which he used synonymously with purpose, as an "*ultimate concern* [emphasis in original]... . A purpose is a deeper reason for the immediate goals and motives that drive most daily behavior" (Damon, 2008, p. 22). Thus, for Damon and his colleagues (2003), purpose is distinct in that it is: (1) an enduring aim; (2) outwardly-oriented or self-transcendent (the *beyond-the-self* component); and (3) directional in that it is an organizing principle, which guides and motivates one's endeavors in life (see also, Bronk, 2014). These outward endeavors motivated by purpose can be referred to as *purposeful engagement* (Bronk, 2014). However, purposeful engagement is not purpose itself but rather the actions spurring from purpose; where purposeful engagement is the "means," purpose is the "ends*"* (Bronk, 2014, p. 109).

While a far-reaching aim, a beyond-the-self orientation, and sustained effort are key in conceptually identifying the presence of one's sense of purpose in life, it is worth noting that the second of these is especially prerequisite to purpose. That is, Damon (2008), along with his colleagues (2003), and Bronk (2014), repeatedly emphasize that the beyond-the-self component is essential to purpose in that a purposeful individual has a steadfast desire and seeks to impact the world "in some personally meaningful way" (Bronk, 2014, p. 111). Frankl (1959/2006) himself strongly espoused the beyond-the-self orientation, or what he referred to as "responsibleness." For Frankl, there is an agentic component to one's *will to meaning* (a term he often used interchangeably with *purpose*), and that agency is found when one devotes oneself in the service of another or of a cause—what he identified as self-transcendence (Frankl 1959/2006, p. 111). However, while Frankl ascribed self-transcendence as a necessary attribute of purpose, the beyond-the-self orientation is not always considered a necessary component for meaning in successive psychology literature. It is thus worth considering some of the prevalent contemporary conceptualizations of meaning.

Meaning

Although Frankl did not distinguish between meaning and purpose, his commentaries on meaning nevertheless inherently point to the dialogical and active sense-making introspection that helps an individual discern the unique meaning of his/her life. Describing the existential rumination he and his fellow inmates needed to engage in during a particularly desperate and hopeless time of their internment, Frankl (1959/2006) offered this explanation of meaning:

> We needed to stop asking the meaning of life, and instead to think of ourselves as those who were being questioned by life—daily and hourly... . Life ultimately means taking the responsibility to find the right answer to its problems and to fulfill tasks which it constantly sets for each individual... . Thus, it is impossible to define the meaning of life in a general way. ... "Life" does not mean something vague, but something very real, concrete, just as life's tasks are also very real and concrete. They form man's destiny, which is different and unique for each individual. (p. 77)

Inherent in Frankl's reflection on meaning is the personal interpretation of one's life experiences, circumstances, and actions as uniquely significant. This perception of personal significance is echoed in subsequent definitions of meaning. For example, Steger, Frazier, Oishi and Kaler (2006) defined meaning as "the sense made of, and significance felt regarding, the nature of one's being and existence" (p. 81).

In his volume of research on meaning, *Meanings of Life*, Baumeister (1991) comprehensively expounds on the various facets of the practice of meaning-making among intelligent beings, like humans. He discusses the various levels of meaning-making from lower levels of forming associations among discrete objects in the physical world or single words and higher-level meanings, which allows for the interpretation of a person's whole life as a "coherent story line." He discusses meaning as an integrative network and framework, in which the various levels of meaning can connect to form higher-level meanings and coherent story lines that also supply lower levels with further meaning: "That is, if your life has a broad, integrative meaning, then most individual acts and events can draw meaning from it" (Baumeister, 1991, p. 21). While Baumeister goes on to further identify how certain types of meaning, like sociocultural or ideological standards, can inform a person's broader, integrative life meaning, it is this notion of drawing meaning through interpretive connections across the discrete components and experiences of one's life that is relevant to distinguishing meaning from purpose.

Perhaps the most clarifying distinction between meaning from purpose comes from Bronk (2014), who juxtaposes the two constructs as follows:

> In other words, for something to comprise a purpose in life it must constitute a far-horizon aim to impact the broader world in some personally meaningful way. Meaning, on the other hand, represents a broader array of goals and interests. People may find meaning in aims that are both other-oriented (e.g. helping others), and purely self-oriented (e.g. becoming wealthy). Further, sources of meaning need not be goal-oriented at all, since *anything that makes one's life more personally significant can be said to be meaningful*. [emphasis added] (p. 111)

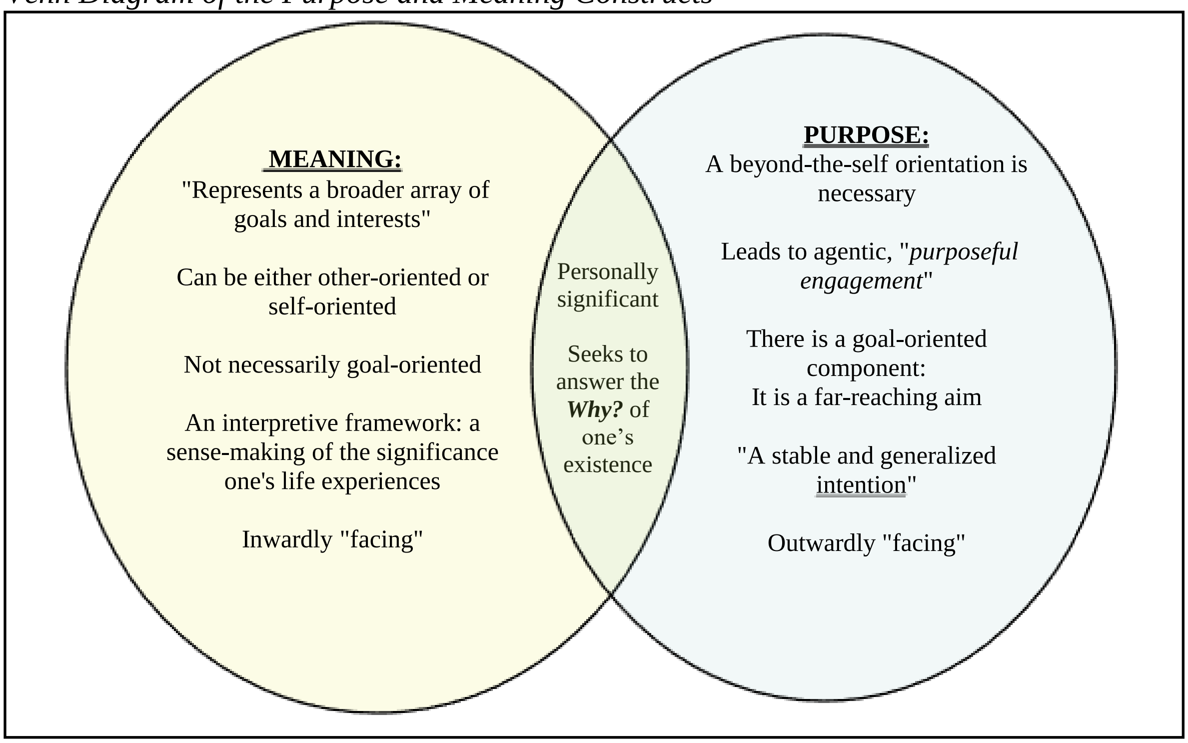
Thus, the crux of meaning lies in the perception of a cohesive personal significance of the constituent parts that make up one's life. The beyond-the-self orientation is not fundamental to meaning; indeed, it could be argued that while purpose is outwardly oriented and the impetus for action, meaning is inwardly oriented and the interpretation of action and experience. However, purpose and meaning are not dichotomous. Indeed, they are symbiotically linked, a relationship that the ensuing discussion expounds upon. Furthermore, this symbiosis arguably stems from the inherent question with which both purpose and meaning are fundamentally concerned: the *Why?* of one's life (Bronk, 2014; Damon, 2008; Frankl 1959/2006). Both constructs manifest in the individual's contemplation of the significance and the reasons for one's experiences and behaviors. Before elaborating upon the dynamic relationship between purpose and meaning, it is perhaps helpful to consider a graphical representation of the similarities and differences between purpose and meaning. Accordingly, Figure 2.2 attempts to summarize the aforementioned conceptualizations into a Venn Diagram.

The Relationship Between Purpose and Meaning

Though distinct, it is perhaps unsurprising that purpose and meaning are often synonymized, given that they are intimately and dialectally related (Bronk, 2014). Baumeister (1991) viewed meaning as comprised of four essential pillars of meaning: purpose, self-worth, values, and efficacy. For Damon and his contemporaries, purpose can also be thought of as a subset of the potential *sources* of meaning in that purpose can lead to a more “diffuse,” overarching sense of meaning to a life (Bronk, 2014; Damon et al., 2003).

Figure 2.2

Venn Diagram of the Purpose and Meaning Constructs



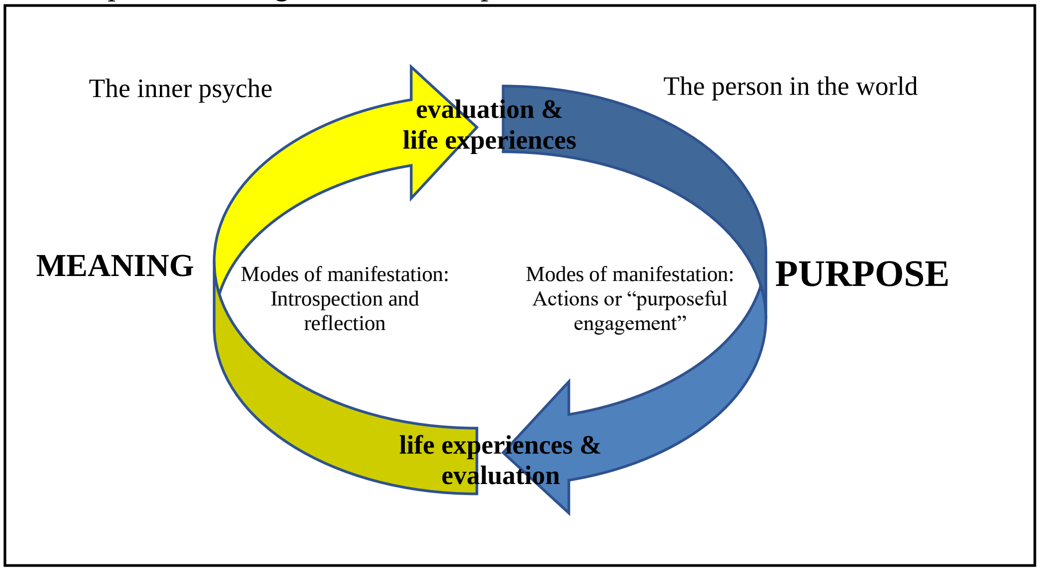
Perhaps one potentially helpful way to describe the relationship of these related constructs is to say that *purpose*, in its far-reaching, goal-directedness nature, gives definition to the more all-encompassing and diffuse experience of meaning. That said, there is a dialogic nature between the two: while purpose can, at least in part, define one's meaning in life, a person's sense of his/her meaning in life can in turn influence the nature of his/her purpose (Bronk, 2014). In this way, it is perhaps useful to think of purpose and meaning as a feedback loop.

Theories of complex adaptive systems (CAS) are instructive in understanding the nature of feedback loops. Synthesizing the works of Weichhart (2013), Chan (2001), and Burns and Knox (2011), complex adaptive systems tend to exhibit the following features: interconnectedness and interaction, non-linearity, feedback loop, active agents, strange attractors, and self-organization and emergence. Interconnectedness and interaction are central to the nature of complex adaptive systems. Complex adaptive systems are interconnected in that elements within the system interact and affect each other (Burns & Knox, 2011; Chan, 2001). However, these interactions need not necessarily be linear; rather, variables within a system can interact in dynamic ways, and the outcome of these individual interactions may not necessarily be predicted (Burns & Knox, 2011; Chan, 2001). These interactions create a feedback loop. Feedback loops emerge when an input into a system causes elements within the system to respond such that this response becomes an output, which in turn becomes an input for another element or for the same element, and so forth.

To say the human person and human behavior are complex adaptive systems is arguably axiomatic. Nevertheless, acknowledging this highlights the dynamic nature of the feedback loop constituted by purpose and meaning, wherein each serve as an input to the other. That is, an individual's sense of purpose may prompt him/her to make intentional decisions about which acts or behaviors to engage in. These behaviors or actions in turn create or inform experiences, which then serve as inputs in the individual's contemplation of the meaning of their life. The sense of meaning may then lead to an evaluation of one's sense of purpose, affirming, challenging, or further informing it. Figure 2.3 illustrates this relationship.

Figure 2.3

The Purpose-Meaning Feedback Loop



Although the discussion around purpose and meaning thus far may be at risk of giving the impression that these constructs are mere ephemeral abstractions of the psyche, it is important to recognize that while these constructs may certainly be forms of high-level cognition, they have important implications for human behavior, development, and learning (Bronk, 2014). This is especially true for adolescents. An ensuing section in this chapter synthesizes the empirical research on the effect and role of purpose on various outcomes of youth development. However, before turning the discussion in that direction, it would be instructive to first consider the theoretical frameworks that further inform the scholarship regarding purpose. In particular, it is worthwhile to consider purpose from the perspective of motivational systems theories, especially as they pertain to learning and education research.

Motivational Systems Theory and Social Purposefulness

Extensive research in educational psychology has repeatedly illustrated the importance and the influence of motivation in learning and academic success. Within this literature, theories of motivation that seek to articulate its various dimensions and forms abound (e.g., Deci & Ryan, 1985; Dweck, 1986; Eccles et al., 1998; Maslow, 1943). Among these, Ford and Smith (2007) proposed an integrative framework that seeks to understand human motivation from a "*person-in-context systems"* perspective (p. 153). They synthesized and conceptualized the key facets of motivation and theoretically and empirically linked it to "optimal human functioning" in their "Thriving with Social Purpose" (TSP) framework. The TSP framework highlights the critical role of purpose and meaning as a fundamental component of optimal human functioning (Ford & Smith, 2007), especially as they concern education and human development. Ford and Smith (2007) operationalize "optimal human functioning" as consisting of two major components: engagement, "the key dynamic in promoting learning, competence development, and improved development," and meaning, "the primary vehicle for promoting a sense of fulfillment, well-being, and personal integrity" (p. 164).

Their integrated systems view of motivation draws from the three major attributes of motivational processes, as defined by Martin Ford's (1992) Motivational Systems Theory (MST):

1. Motivational processes are qualities of the person rather than properties of the context.
2. Motivational processes are future oriented rather than being focused on the past or present.
3. Motivational processes are evaluative rather than instrumental in character. (p. 72).

In the MST view, motivation is the function of three major interrelated and dynamic psychological processes, which are collectively referred to as "the motivational headquarters," and are comprised of personal goals, personal agency beliefs (which include beliefs about capability and context), and emotions (Ford & Smith, 2007). In expounding upon the personal goals dimension, Ford & Nichols (1991) proposed "The Ford and Nichols Taxonomy of Human Goals." This taxonomy categorizes human goals within six major domains: integrative social relationship goals, self-assertive social relationship goals, affective goals, cognitive goals, task goals, and subjective organization goals. Nested within these domains are a varying number of subcategories (see Table 2.1). For example, aspirations that fall under that "integrative social relationship goals" domain (also the domain of interest in this study) can be further categorized into goals related to belongingness, social responsibility, equity, and resource provision (Ford & Nichols, 1991). While Ford and Nichols' taxonomy is not necessarily hierarchal in nature, Ford and Smith (2007) do posit that the "integrative social relationship" domain may be the most integral of these domains with its potential to magnify all other domains and the entire motivational system.

Table 2.1

Ford & Nichols' Taxonomy of Human Goals from the Motivational Systems Theory. (Adapted from Ford & Nichols, 1991)

Integrative social relationship goals	
Belongingness	Building or maintaining attachments, friendships, intimacy, or a sense of community, avoiding, feelings of social isolation or separateness.
Social Responsibility	Keeping interpersonal commitments, meeting social role obligations, and conforming to social and moral rules, avoiding social transgressions, and unethical or illegal conduct
Equity	Promoting fairness, justice or equality; avoiding unfair or inequitable actions
Resource Provision	Giving approval, support, assistance, advice, or validation to others; sharing or contributing intellectual, material or emotional resources with partners or collaborators; avoiding selfish, uncaring or uncollaborative behavior.
Self-assertive social relationship goals	
Individuality	Feeling unique, special, or different; avoiding similarity or conformity
Self-determination	Experiencing a sense of freedom to act or make choices; avoiding the feeling of being pressured, constrained or coerced
Superiority	Comparing favorably to others in terms of winning, status, or success; avoiding unfavorable comparisons with others
Resource acquisition	Obtaining approval, support, assistance, advice, or validation from others; acquiring intellectual, material, or emotional resources from partners or collaborators; avoiding social disapproval, rejection, or exclusion
Affective goals	
Arousal	Experiencing excitement or heightened arousal; avoiding boredom or stressful activity
Tranquility	Feeling relaxed and at ease; avoiding stressful overarousal
Happiness	Experiencing feelings of joy, satisfaction, or well-being; avoiding feelings of emotional distress or dissatisfaction
Bodily sensations	Experiencing pleasure associated with physical sensations, physical movement, or bodily contact; avoiding unpleasant or uncomfortable bodily sensations
Physical well-being	Feeling healthy, energetic, or physically robust; avoiding feelings of lethargy, weakness or ill health

Table 2.1, *cont.*

Cognitive goals	
Exploration	Satisfying one's curiosity about personally meaningful events; avoiding a sense of being uninformed or not knowing what's going on
Understanding	Gaining knowledge or making sense out of something; avoiding misconceptions, erroneous beliefs, or feelings of confusion
Intellectual creativity	Engaging in activities involving original thinking or novel or interesting ideas; avoiding mindless or familiar ways of thinking
Positive self-evaluation	Maintaining a sense of self-confidence, pride, or self-worth; avoiding feelings of failure, guilt, or incompetence
Task goals	
Mastery	Meeting a challenging standard of achievement or improvement; avoiding incompetence, mediocrity, or decrements in performance
Task creativity	Engaging in activities involving artistic expression or creativity; avoiding tasks that do not provide opportunities for creative action
Management	Maintaining order, organization, or productivity in daily life tasks; avoiding sloppiness, inefficiency or disorganization
Material gain	Increasing the amount of money or tangible goods one has; avoiding the loss of money or material possessions
Safety	Being unharmed, physically secure, and free from risk; avoiding threatening, depriving, or harmful circumstances
Subjective organization goals	
Unity	Experiencing a profound or spiritual sense of connectedness, harmony, or oneness with people, nature, or a greater power, avoiding feelings of psychological disunity or disorganization
Transcendence	Experiencing extraordinary states of functioning; avoiding feeling trapped within the boundaries of ordinary experience

Ford and Smith (2007) thus proposed that the inherently social nature of humans makes a goal orientation toward interpersonal connectedness, or social purpose, especially key in understanding motivation and optimal functioning. Their review of the literature regarding the positive effects of socially purposeful goals on health, motivation in youth, and happiness led them to observe:

> It appears that the reverberating effects of socially purposeful actions such as engaging in authentic helping, exercising effective leadership, striving for social justice, and investing in significant relationships can be motivationally contagious and extraordinarily meaningful whether one is the initiator or the recipient of such actions. (Ford & Nichols, 2007, p. 164)

Like Ford and Smith (2007), Chulef, Read, and Walsh (2007) discussed the importance of socially-oriented goals. Chulef et al. (2007) constructed a hierarchal taxonomy of goal domains after studying the goal-importance rating of over a hundred men and women between the ages of 17 and 75. Their findings showed that after the broader cluster of "family, marriage, sex & romance," the majority of participants identified "interpersonal goals" as second most important, followed by "intrapersonal goals." Goals and motivation play an important role in the formation of self-concept and aspirations, including career aspirations and how an individual might respond to these aspirations. One theory that is particularly helpful in elucidating the intersection of goals, motivation, self-concept, and career aspirations is Markus & Nurius' (1986) Possible Selves theory. Given that purposefulness and purposeful engagement are intimately linked to motivation, goals and aspirations, and self-concept, Possible Selves theory also has many implications for understanding youth purposefulness.

Possible Selves Theory

Originating from the school of cognitive psychology, possible selves theory emphasizes future-oriented self-concepts and focuses on one's understanding of one's own potential (Markus and Nurius 1986). Markus and Nurius (1986) explain the notion of the possible self as "the ideal selves that we would very much like to become. They are also the selves we could become, and the selves we are afraid of becoming" (p. 954). While the implications of Possible Selves theory are many, the facet of this theory most pertinent to the present study is that which relates to motivation. Depending on the specific conception of the possible self, the possible self can "provide a direction and impetus for action, change and development" (Markus & Nurius, 1986,

p. 960). The possible self can thus frame motivation within a goal versus threats orientation and can impact decision-making (Markus & Nurius, 1986). As such, the Possible Selves theory has been widely applied to research on career development and aspirations. For example, Pizzolato (2007) examined the coping mechanisms, persistence, and possible-self retention of 32 college students who were confronted with circumstances where their career possible-selves bordered on impossible. Similarly, Chalk et al. (2005) applied this theory to their study on college women's occupational fears and aspirations. Thus, the possible selves theory provides a framework through which we can understand how career trajectories first take shape in the mind.

Possible Selves theory has also often been used symbiotically with Linda Gottfredson's circumscription and compromise theory (Pizzolato 2007; Chalk et al. 2005), in which Gottfredson proposes four processes of cognitive development. Pizzolato (2007) summarizes them as follows:

> According to Gottfredson (1981, 2004), career development involves four processes: (a) cognitive growth: developed ability to think complexly and abstractly about options and goals; (b) self-creation: internal definition of who one wants to be and why—construction of aspirations; (c) circumscription: narrowing possible aspirations by eliminating less desirable or prestigious choices; and finally (d) compromise: making a final match, sometimes between less desirable options by choosing what is good enough. (p. 202)

Of key importance here are the first and second processes of cognitive growth, which involve the ability to perceive and comprehend options and goals and to determine how those options and goals align with self-definition or self-determination. Gottfredson (1981) discusses other research that shows that adults and children alike can consistently group and rank occupations, based on titles alone, similar to how incumbents in those occupations would respond to the same task, though the ability to describe an occupation with sophistication increases with age. Even so, there still exists a tendency for both adults and children to associate an occupation with the lifestyle characteristics it affords and the social implications associated with it more than the actual duties or nature of the job:

> It appears then, that neither children nor adults know much about job tasks and requirements, but they certainly possess a common general understanding of what it means socially and economically to have different jobs. Their cognitive map of occupations is largely a map of social relations and life styles, which suggests that the social identity conferred by occupations is clear and of great concern to people. (Gottfredson, 1981, p. 551)

With regard to youth purpose, then, possible selves theory and Gottfredson's four processes of career development suggest that if a young person perceives certain career options as contributing to his/her sense of purpose in life or affording him/her a lifestyle that would allow him/her to foster his/her sense of purpose, then said career options may become *possibilities* for the future self in his/her mind. In other words, if alignment between one's career and purpose-in-life is a priority or a desirable facet of one's future self, career options that may offer this alignment are more likely to be internalized and prioritized as possible future selves.

Having expounded upon the theoretical constructs and dynamics that inspired and informed the basis of this research, it is now worth considering the past empirical research that examined the importance of purpose to youth thriving.

Motivation, Purpose and Youth Thriving

Over the past three decades, social cognitive theory has elucidated the effects of motivation on student achievement and learning, highlighting the significant roles an individual's beliefs, achievement values, goals and interests can play in his or her academic achievement (McCombs, 1991; Wigfield & Cambria, 2010). Indeed, McCombs (1991) and Maton (1990) found that a sense of personal relevancy and meaningfulness, especially as it pertains to student interests and goals, is a crucial aspect of the optimal conditions for learning and overall well-being in youth. In light of these theories highlighting the importance of motivation, especially motivation as a sense of purpose, it is important to consider how the beyond-the-self orientation or socially purposeful aspirations may correlate with or impact learning, academic achievement, overall youth thriving, and career aspirations.

As it pertains to the purpose-in-life construct more specifically, having a sense of purpose has been linked to many facets of optimal human functioning including physical, social emotional, and psychological health (Bronk, 2014; Ford & Smith, 2007). In particular, past evidence suggests that a sense of purpose can positively impact adolescents and young adults as they negotiate the specific developmental tasks and experiences that define their youth.

A leading scholar in the purpose literature, Bronk (2011; 2014) explained how purpose is instrumental to what Erikson (1958) identified as the key developmental task of adolescence, identity formation. Prefacing her own research into the relationship between purpose and identity, Bronk (2011) discussed how Erikson himself suggested that purpose and identity inform each other and develop together. Bronk empirically investigated the relationship between purpose development and identity formation in youth in a multi-stage, longitudinal, in-depth case study of eight youth ranging in age between 12 and 22 years old at the start of the study. The participants represented exemplars of purpose and emerging adulthood. The results of this study indicated three prominent themes that describe the inherently dialectal relationship between purpose and identity formation: the first is that purpose encourages identity formation; secondly, identity formation reinforces purpose-commitment; and thirdly, purpose and identity appear to be overlapping constructs (Bronk, 2011). Thus, among youth, purpose is intimately linked to their likelihood of forming a strong, or even a stable, sense of identity (Bronk, 2011; Erikson, 1968; Yeager & Bundick, 2009).

The impact of purpose on youth's learning and academic achievement has also been the focus of several empirical investigations. Yeager and his colleagues (2009; 2016), for example, have conducted a series of studies that have investigated the influence of purpose in various aspects of adolescents' academic experience. In a mixed methods investigation of the role of purpose in promoting a sense of meaning-in-life and improving schoolwork among a diverse sample of 148 middle and high school youth, Yeager and Bundick (2009) found that compared to peers with self-oriented or extrinsically oriented work goals, youth who had purposeful work goals (which the authors operationalized as intrinsic, beyond-the-self oriented occupational goals) tended to have a greater sense of meaning in life, higher sense of purpose in life, and were more likely to perceive doing homework and schoolwork as being meaningful to them. That is, they found a statistically significant positive relationship between purposeful work goals with: meaning-in-life, purpose-in-life, and perceived meaningfulness in schoolwork/homework (Yeager & Bundick, 2009). In summarizing the implications of their findings, Yeager and Bundick (2009) noted, "These results suggest that a complete account of how work goals relate to eudaimonic well-being and academic motivation in adolescence might also consider the development of adolescents' purposeful intentions to accomplish something of consequence in the world" (p. 445).

More recently, Yeager et al. (2016) conducted a four-part study to examine how self-transcendent (or beyond-the-self) purpose for learning could potentially improve academic self-regulation and persistence, especially with boring, tedious tasks. After studying a combined total of over 2,000 adolescents and young adults, Yeager and colleagues found that a self-transcendent purpose correlated with greater academic self-regulation and persistence, even when the task was boring and when other, more entertaining distractions were available. Furthermore, in probing the causal effect of notions of purpose on positive academic behaviors, Yeager et al. (2016) found that a brief experimental intervention prompting students to reflect on potential prosocial, self-transcendent purposes for learning helped improve the science and math GPAs of urban, low-income high school students. Similarly, they found that cultivating a sense of self-transcendent purpose promoted deeper learning during tedious tasks like studying for an exam. In contrast, results from the control and comparison groups, who did not engage in explicit reflections on self-transcendent purposes for learning, showed that self-oriented motivations for learning predicted various positive academic outcomes far less consistently and frequently. Wittily referencing one of Frankl's most quoted insights, Yeager et al. (2016), summarized their collection of findings in this way: "All told, it seems that when adolescents had a personally important and self-transcendent 'why' for learning they were able to bear even a tedious and unpleasant 'how' (cf. Frankl, 1963)" (p. 574). Other studies have similarly shown how purpose is positively and statistically significantly related to self-efficacy (DeWitz et al., 2009) and grit among college students (Hill et al., 2016; Lund et al., 2019). Thus, it appears that promoting notions of prosocial self-transcendent purpose, or social purpose, can have important implications in fostering positive academic and learning behaviors.

There are also important implications in the role purpose plays for the learning and academic achievement of disadvantaged youth. For example, in their study of the relationship between purpose, perceived control, and academic achievement of predominantly low-income, racial minority students, Pizzolato and her colleagues (2011) offered further insight into the potential factors that perpetuate the academic achievement gap for low-income and minority youth. More specifically, their study examined the effects of an intervention aimed at increasing the sense of purpose and self-efficacy (internal control over academic achievement) among 170 students who were identified as having low scores (one to two standard deviations below the mean) on both these measures. They not only observed significant increases in a sense of purpose as well as internal control among students receiving the intervention, but these gains were also associated with notable increases in students' GPAs (Pizzolato et. al, 2011). Evidence such as this suggest that a sense of purpose has important implications for promoting positive youth development, especially as it may pertain to their academic success. Furthermore, these findings suggest that more concerted efforts to centralize and foster youth purpose within students' learning contexts are needed to facilitate these benefits.

Pedagogies of Youth Purpose

Project-Based Instruction (PBI) and Youth Purpose

Given the burgeoning evidence for the instrumental role purpose can have in facilitating student success, in recent years, there have been growing explorations into the mechanisms that might allow schools and teachers to effectively design learning experiences that foster and leverage youth purpose in an academic context. Dr. Heather Malin's 2018 book *Teaching for Purpose: Preparing Students for Lives of Meaning* speaks directly to this purpose. In it, Malin (2018) endorses project-based instruction (or project-based learning) as a pedagogy of purposeful instruction. Citing the putative "father" of modern-day project-based learning William Heard Kilpatrick (1918), Malin (2018) explains how Kilpatrick's vision for "*the project method"* was inherently premised on "students having a purpose for learning, which they do by planning and implementing projects that fulfill their life purpose" (p. 137).

With this in mind, it is worthwhile to briefly consider the salient features that underscore project-based instruction (PBI). Despite the lack of a singular definition for PBI, there is nevertheless consensus that at least six essential elements distinguish true PBI from other, misappropriated versions of it: a driving question or anchor; focus on learning goals; student participation in disciplinary practices; collaboration and/or cooperation; scaffolding; use of cognitive or learning tools and technologies; and a tangible, final product or artifact (Krajcik &

Shin, 2014; Marshall et al., 2010; Hasni et al., 2016). Other scholars also argue that additional defining qualities of PBI include student-centeredness and authenticity to the project context (Blumenfeld et al., 2000; Kokotsaki et al., 2016; Thomas, 2000;).

Synthesizing the research on youth purpose development, Malin (2018) outlined seven elements of *purposeful projects* which, in essence, consist of principles for project-based learning, that may better support students' purpose development. These seven elements of purposeful projects are:

1. Purposeful projects are meaningful to students.
2. Purposeful projects are inquiry-driven.
3. Purposeful projects are sustained over time.
4. Purposeful projects involve reflection throughout.
5. Purposeful projects are collaborative and community building.
6. Purposeful projects elevate students' social awareness.
7. Purposeful projects set high expectations for students. (Malin, 2018, pp. 140–143)

Perhaps unsurprisingly, these seven elements closely parallel the six elements of PBI noted previously. Thus, it seems as though there may be an almost ipso facto purpose-orientation to an authentic implementation of project-based instruction.

Service-Learning and Youth Purpose

The purpose literature is also replete with scholars espousing the use of the service-learning pedagogy as a pedagogy to foster youth purpose. Indeed, Moran (2018) named service-learning as the most likely pedagogy to underscore and cultivate all dimensions of purpose. This is likely because a beyond-the-self orientation is at the core of the service-learning pedagogy (Malin, 2018; Moran, 2018). Furthermore, Moran (2018) theorized that purpose and service have a reciprocal relationship that can be conceptualized as a feedback loop model. Describing how prosocial intentions and behaviors can affect *the common good*, which in turn can have a ripple effect that ultimately reinforces one's desire to positively contribute to the community, Moran (2018) explained how community service exemplifies this feedback loop mechanism:

> Community service work is an action aimed to have prosocial effects on other individuals and the common good so it is particularly amenable to demonstrating the model (Moran, 2017b, under review). Even if a student has not already committed to a purpose, community service work could result in feedback on the student's efforts that the student perceives as making a difference in others' well-being, which could generate emotional meaning for the student and generate intentions to contribute in the future. In addition, repeated interactions of meaning, intention and feedback on prosocial effects could catalyze development of a life purpose. (p. 150)

In essence, theoretically, community service can be the mechanism by which purpose develops. This premise, taken together with Malin's (2018) framework purposeful projects, gives credence to the hypothesis that project-based service-learning can be a pedagogy of youth purpose. Indeed, this hypothesis is not only at the core of this thesis, but it is also a focus of a current, ongoing multinational research effort, led by Moran and eight other scholars from six countries (learning4purpose.org, 2020).

At the time of writing this thesis, the results of their empirical investigations into service learning as a pedagogy for youth purpose were still forthcoming, but one other study (independent of the learning4purpose coalition) examined the influence of high school youth's service-learning experiences in a program called PeaceJam and the youth's development of purpose (Jones, 2017). After surveying 147 PeaceJam youth participants and interviewing 30 of them, Jones (2017) found that at least a third of students reported that the service-learning experience helped them reflect on and better identify a purpose-in-life. At least 36% of the study participants said that the service-learning experience was personally meaningful to them. The survey and interview data also showed that the PeaceJam experience promoted increased intentions to commit to future service activities, particularly within a future academic setting. Furthermore, the PeaceJam experience seemed to positively impact academic engagement for several youth, helping bolster motivation, a sense of personal relevance in school work, and even attitudes toward school (Jones, 2017). However, it is important to note that while these outcomes were observed for a number of the study participants, these perceptions and sentiments were not necessarily universal among them; a fair number of participants also reported little to no change in the domains of purpose, commitment to service, and academic engagement as well (Jones, 2017). Nevertheless, Jones' (2017) study still serves as an important exemplar of the type of research needed to further investigate the role and design of service-learning experiences in influencing positive youth development and academic engagement.

Frameworks for Pre-College Engineering Education

The third body of literature that informs this dissertation comes from the corpus of engineering education research, namely that of pre-college engineering education research. Although relatively newer in comparison to research on engineering education in higher education contexts, the pre-college engineering education literature has nevertheless burgeoned within the past decade or so as the growing interest and need for K-12 engineering education has become increasingly more apparent. Among these efforts has been those that aim to better identify and articulate guiding principles for quality pre-college engineering education. In 2009, the National Academy of Engineering (NAE) itself undertook to scope the landscape of pre-college engineering education, at the time, and to identify some key principles to direct future efforts. These principles were as follows:

> Principle 1. K–12 engineering education should emphasize engineering design.
> Principle 2. K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.
> Principle 3. K–12 engineering education should promote engineering "habits of mind." (Katehi et al., 2009)

Principles 1 and 2 in this framework deserve further elaboration. More specifically, it is important to better articulate some of the salient characterizations of what constitutes the "engineering design process," and engineering "habits of mind." Katehi et al. (2009) defined engineering design as "a purposeful, iterative process with an explicit goal governed by specifications and constraints" (p. 82). Further elaborating on the notion of this iterative process, they highlight that extant conceptualizations of the engineering design process (EDP) tend to consist of at least these general steps:

1. Identify the problem or objective.
2. Define goals and identify the constraints.
3. Research and gather information.
4. Create potential design solutions.
5. Analyze the viability of solutions.
6. Choose the most appropriate solutions.
7. Build and implement the design.
8. Test and evaluate the design.
9. Repeat all steps as necessary. (Katehi et al., 2009, p. 83)

While these nine steps may offer but one model of the engineering design process (EDP), several conceptualizations of the EDP abound, as well as various *types* of models (such as a phase-based, vs. activity-based) (Tate et al., 2010). Nevertheless, most EDP models in the literature incorporate nine core verbs ("identify," "define," "research," "create," "analyze," "choose" "build," "test & evaluate," and "repeat/iterate"), or synonyms thereof, along some stage of the model.

As it regards engineering "habits of mind," there are similarly varying lists of what constitutes said habits. However, Katehi et al. (2009) identified "(1) systems-thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations" (p. 152) as the six core habits of mind. The identification of these "habits of mind" intend to encourage learners toward appreciating and adopting the interconnected approach necessary, both within the design process itself and in working with collaborators and stakeholders and in creativity and perseverance that an engineering mindset entails.

Other engineering education researchers have also attempted to define guiding principles for effective pre-college engineering education. In discussing the UTeachEngineering program, one of the flagship movements in pre-college engineering education, instituted by the University of Texas at Austin, Marshall and Berland (2012) echoed the NAE's principles (Katehi et al., 2009), particularly highlighting the importance of emphasizing to young learners the epistemologies that make engineering a distinct endeavor, such as the engineering design process and engineering habits of mind:

> For example, this work posits that that [sic] a primary goal of pre-college engineering education is for students to develop a command of the engineering design process and engineering habits of mind and that traditional math and engineering class. This is an important commitment... . Our contention is that they cannot be a side-note in traditional math and science classes. (p. 49)

Elsewhere, Berland (2013) elaborated on this stance for engineering curriculum design, outlining the six principles that had guided the development of UTeachEngineering's *Engineer Your World* curriculum:

1. Contextualize all student work within STEM-design challenges.
2. Specify specific course and unit learning goals.
3. Employ a standardized engineering design process as an instructional framework.
4. Engage students in sensible forms of engineering practices from day one.
5. Ensure that all science and math concepts, and technology tools employed are necessary for students' successful completion of the STEM-design projects.
6. Attend to the constraints of high school and school district systems. (p. 23)

Perhaps the most comprehensive framework that attempts to outline the features of quality pre-college engineering education comes from Moore et al. (2014). Undertaking a comprehensive literature review, consultation of standards from professional engineering organizations as well as expert engineers, and design-and-evaluation iterations of the framework, Moore and her colleagues (2014) proposed 12 key indicators of quality pre-college engineering education. These 12 indicators are outlined in Figure 2.4.

Figure 2.4

Framework for Quality K-12 Engineering Education. (Adapted from Moore et al., 2014)

Key Indicators

- Process of Design (POD)
  - Problem and Background (POD-PB)
  - Plan and Implement (POD-PI)
  - Test and Evaluate (POD-TE)
- Apply Science, Engineering, and Mathematics (SEM)
- Engineering Thinking (EThink)
- Conceptions of Engineers and Engineering (CEE)
- Engineering Tools (ETool)
- Issues, Solutions, and Impacts (ISI)
- Ethics
- Teamwork (Team)
- Communication Related to Engineering (Comm-Engr)

It is important to note that while these 12 key indicators are all important facets of pre-college students' engineering education experiences, all 12 of them do not necessarily need to be incorporated into a single lesson or even a single unit. Rather, the authors suggest that these 12 indicators must be present at some point throughout a student's pre-college engineering education career (Moore et al., 2014).

Comparing these various frameworks, it becomes apparent that the most essential feature for pre-college engineering curriculum design is the engineering design process (EDP). There appears to be a consensus that a quality engineering education affords young learners the opportunity to not only learn about but also experience the engineering design process.

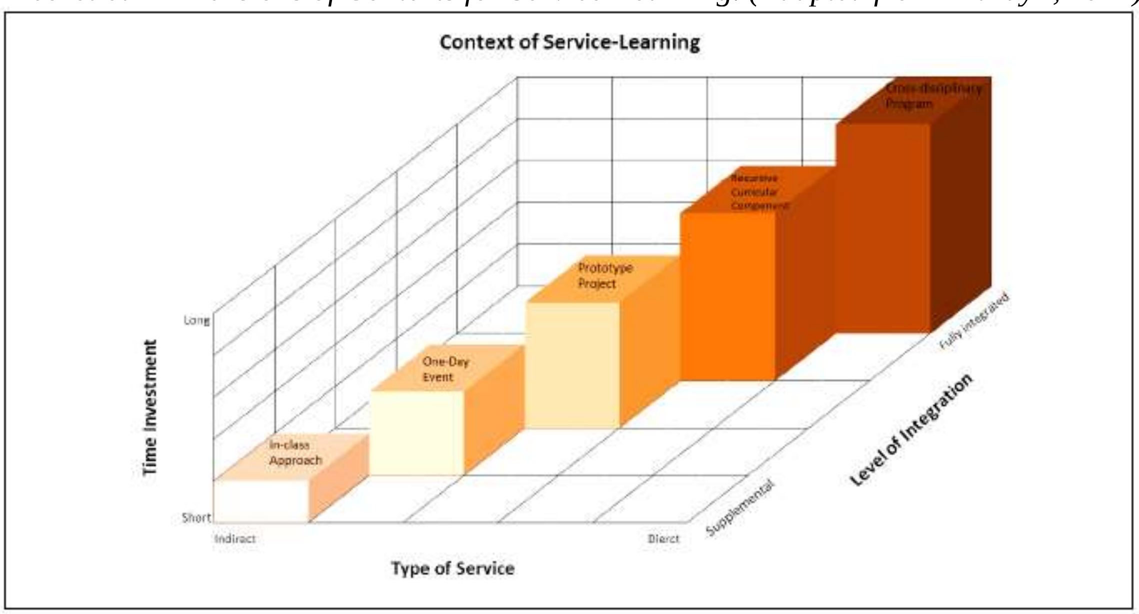
Service-Learning and Engineering Education

Conceptualizing the Intersection of Service-Learning and Pre-College Engineering Education

In my own previous work (Tharayil, 2017), I undertook to synthesize some of the theoretical literature on service-learning and pre-college engineering education to explore their intersections, particularly from a curriculum design standpoint. I therein theorized this intersection as a series of decisional spectra that centered around the context for service learning, project selection, and assessment. The possibilities for the context of a pre-college service-learning experience can be conceptualized as being located within a three-dimensional theoretical space comprised of the following axes: “1. the type of service (direct vs. indirect) 2. the level of integration and (fully integrated vs. supplemental) 3. the time investment (long vs. short).” Refer to Figure 2.5 for explanation (Tharayil, 2017).

Figure 2.5

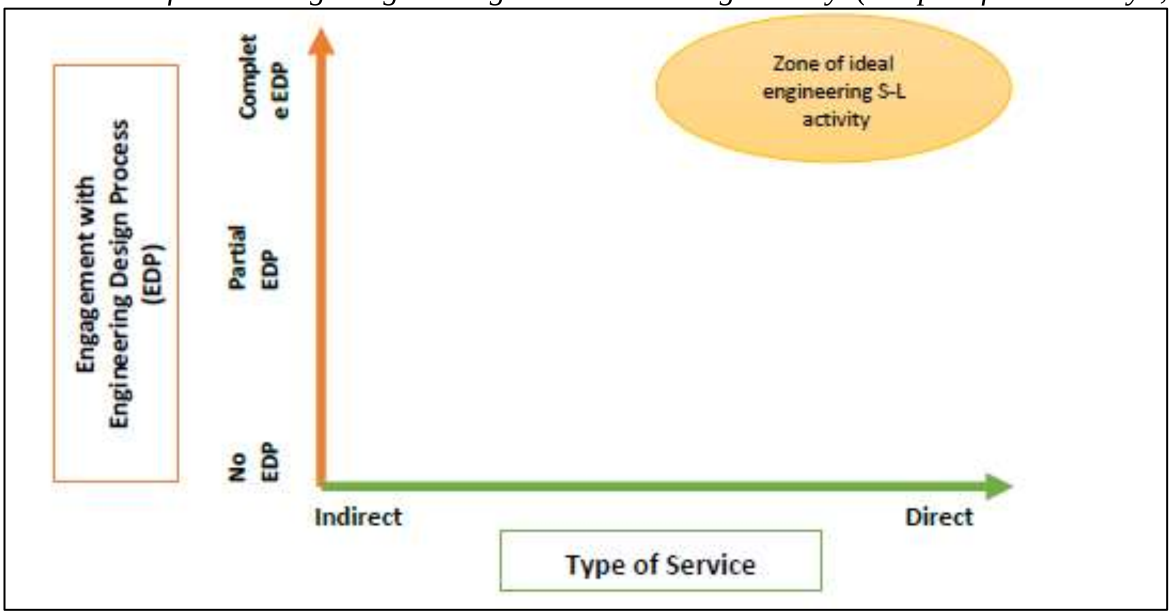
Theoretical Dimensions of Contexts for Service-Learning. (Adapted from Tharayil, 2017)



These axes of time investment, type of service, and level of integration can be thought of as “meta-axes,” as other considerations of context are often nested within these. For example, in thinking about project-based service-learning (PBSL) for pre-college engineering education, in particular, it is important to consider both the level of integration engineering enjoys within the school curriculum as well as the level of engagement with the engineering design process the service-learning experience project would afford, which in itself can be conceived as the interaction between type of service and time investment (Tharayil, 2017). This continuum of pre-college engineering service-learning activity is pictured in Figure 2.6. Figure 2.6 also depicts a theoretical "zone of ideal engineering service-learning activity." This zone is the theoretical zone in which I propose that the most ideal form of pre-college engineering service-learning is that which affords students the opportunity to experience the complete EDP cycle and direct service with the community partner (Tharayil, 2017).

Figure 2.6

Continuum of Pre-College Engineering Service-Learning Activity. (Adapted from Tharayil, 2017)



Project selection is dependent on the point of convergence along three decisional continua: resource availability, constituent choice, and student capacities. Finally, assessment decisions for pre-college PBSL engineering units appear to fall along a spectrum of standardized/traditional assessments versus performance-based/portfolio assessments (Tharayil, 2017).

Engineering Outcomes of Project-Based Service-Learning

Outcomes in the Pre-College Context

Thus far, empirical investigations into the engineering outcomes afforded by pre-college service-learning experiences have been scarce. In this section, the results of only two such studies are recounted, but more evidence exists about learning in engineering in the higher education contexts and is briefly summarized herein. It is nevertheless worthwhile to first consider whatever evidence does exist within the pre-college context. Neman, Dantzler, and Coleman (2015) conducted a large mixed methods study examining the relationship between at-risk middle school students' participation in a STEM service-learning project and their academic engagement in science, their resilience, and their sense of civic responsibility. The participants in this study included over 6,000 middle school students from 20 schools, and the measures included pre- and post- surveys, interviews, focus groups, observation and field notes, and content analysis of student journals. The results showed that after one year of participating in the STEM service-learning project, students demonstrated gains in all three outcomes, especially with teachers' and students' perceived improvements in students' academic engagement, an increased sense of civic responsibility, and statistically significant increases in female students' resiliency scores ($p<.001$).

Another comprehensive study by Zarske (2012) most closely parallels that of this present research. Zarske explored the impacts of PBSL engineering experiences on high school students' and first-year engineering students' identities in and attitudes toward engineering and service. Of specific interest here, though, are her findings on the effects of PBSL engineering experiences on the high school students' engineering attitudes and identities. Using a pre-/post- design, Zarske administered an engineering attitudes scale to 102 high school students in a STEM academy that offered a three-year course sequence in engineering. She found that participation in the PBSL engineering experience was significantly related to an increased sense of engineering identity, which was especially true for students who belonged to underrepresented minority groups. However, a “ceiling effect” was observed, in that engineering identity scores appeared to increase more so within the first year and plateau over successive years (Zarske, 2012). Though there was more variability in the models predicting the influence of PBSL and students’ service attitudes, students with initially lower service attitudes appeared to have a greater increase in service attitude scores over time. However, Zarske also posited that there was perhaps a “ceiling effect” on service attitudes in that students who scored higher on service attitudes before the service-learning experience were already service-oriented and therefore there was less room to grow in this regard (Zarske, 2012).

Outcomes in the Higher Education Context.

The increasing integration of service-learning in undergraduate engineering education has unsurprisingly spurred interest in the specific benefits such a pedagogy can offer. Such interest is heavily motivated by the various decidedly positive outcomes for students, faculty, and institutions, as well as community partners, and repeatedly perceived and avowed by engineering education scholars and faculty within the growing literature on engineering service-learning (Bielefeldt & Pearce, 2012; Swan et al., 2010). Research has demonstrated that service-learning pedagogies tend to be at least equally as effective in helping engineering students gain important knowledge and skills as traditional educational models, if not more so (Bielefeldt & Pearce, 2012; Swan et al., 2010), but with added positive impacts on students’ moral development, interpersonal skills, and their ability to apply what they learn to real-world contexts (Bielefeldt & Pearce, 2012).

In their comprehensive survey of the engineering education service-learning literature, Bielefeldt and colleagues (2010) identified a number of specific student outcomes that past research had shown to be particularly promoted by service-learning (SL). Bielefeldt and her colleagues (2010) found that past engineering education research showed that engineering students' learning seemed to profit from SL in at least the following ways: progress toward ABET student outcomes, which outline the accreditation standards for undergraduate engineering programs in the United States; deeper cultural competency; increased self-efficacy, self-confidence, self-esteem; improved critical thinking and scientific reasoning; improved engineering identity; development of leadership skills; and increased creativity and creative design.

Another case study, conducted by Mostafavi et al. (2016) on perhaps one of the most renowned service-learning engineering programs in Purdue University's EPICS (Engineering Projects in Community Service), generated further insights into some of these positive outcomes of service-learning. Mostafavi and colleagues (2016) examined the EPICS program, at large, in order to determine how its fundamental PBSL pedagogy allowed civil engineering students progress toward the American Society of Civil Engineers' (ASCE) Body of Knowledge (BOK) and ABET outcomes. The authors examined, in particular, two Habitat for Humanity (HFH) sustainability projects, one conducted in Indiana and one conducted in Haiti. Mostafavi and his team conducted a content analysis of an array of programming and curricular documents as well as student work and reflections to find evidence of student progress toward these outcomes. From this review, Mostafavi et al. found that students grew in competencies related to foundational, technical, and professional skills. In both HFH projects, students learned and applied principles of mathematics and natural sciences—for example, using statistical analyses in the local project, and principles of heat transfer in soil for the global project—engineering in the context of the problems related to the communities, such as energy modeling in the local project and geotechnical engineering, hydraulics, and decision analysis in the global project; project design and project management skills such as scope definition, scheduling, budgeting, stakeholder management, etc.; teamwork and leadership skills; and ethical reasoning and professional responsibilities. Based on these findings, Mostafavi et al. (2016) concluded that students made sufficient progress toward the ASCE-BOK and ABET outcomes as a result of the PBSL model of the EPICS program. They posit that two fundamental features of PBSL engineering curriculum are necessary for students to achieve such learning outcomes: the first is that PBSL allow students to design in a real-world context, while the second is that critical and reflective thinking are fostered in such realistic contexts (Mostafavi et al., 2016).

Several other scholars have also explored the influence of service-learning on broader academic outcomes in higher education. For example, Song et al. (2017) conducted one such study, analyzing the academic records of 5,368 students at a large Midwestern university in the United States. Of these students, 2,731 had enrolled in one or more courses with a SL component during their first four years of college, while 2,637 students had not. Song et al. (2017) ran a series of regression models (least squares as well as logistic regression) to determine where any relationship existed between service-learning and cumulative GPA, units earned, retention, or graduation rates. These regression models showed that for students in science and engineering ($n= 871$), service-learning had statistically significant and strong positive relationships with the student's GPA ($B=.10$, $p<.01$), units earned ($B = 3.62$, $p<.05$), and retention ($B= 1.36$, $p <.001$), as well as graduation ($B=.88$, $p<.001$). Perhaps even more compellingly, in disaggregating their data further, Song et al. (2017) found that SL also had a statistically significant positive relationship with the retention of underrepresented students in science and engineering ($n = 311$, $B=1.05$, $p<0.05$). Although the present discussion only focuses on Song et al.'s (2017) findings for science and engineering majors, their original article provides a more exhaustive report of the regression results for their university-wide sample, which includes students of all majors and demographic characteristics.

Conclusion

Taking together the theoretical rationales as well as some of the past empirical evidence presented here, it appears that the project-based service-learning model holds the potential of being a particularly compelling pedagogical context for pre-college engineering education. While educational psychology literature seems to espouse it as a prime pedagogy for fostering youth purpose, evidence from engineering education research has repeatedly showcased its benefits at the higher education level as well. Thus, the extant literature between these disciplines not only provides encouraging precedents for the present research, but it also informs its design heavily. The next chapter describes the research design and methods for this dissertation.

CHAPTER THREE:
METHODS

To explore the research questions, the methods described in this chapter draw from the case-study and design-experiment methodologies. As such, this research is perhaps best characterized as a "case study of a design experiment." It is a case-study in that this research "involves the study of a case within a real-life contemporary context or setting" (Creswell, 2013), namely the enactment of a project-based service-learning (PBSL) engineering design unit in a sixth-grade Catholic elementary school classroom. More specifically, while this study is primarily an intrinsic case study due to its exploratory nature (Creswell, 2013; Mills et al., 2010), it nevertheless resembles features of an instrumental case study in that it also aims to further inform theory (Creswell, 2013; Mills et al., 2010), specifically curriculum theories pertaining to pre-college engineering education and youth-purpose development.

This research is also couched within the design experiment/design-based research methodology. Design experiments seek to intersect theory and praxis and locate the research within the classroom setting, taking into account the complexity of these learning contexts (Brown, 1992; Collins, 1990). Furthermore, design experiments and the related design-based research (DBR) methodology necessarily admit the researcher into an intimate involvement with the classroom community of interest, wherein she becomes simultaneously a researcher and a participant in the study (Barab, 2014). With these methodological aims in mind, this chapter explicates the setting and context of the research, the participants, the instruments and data sources, and the methods of analysis undertaken to explore the research questions:

1. How, if at all, does participation in a K–12 PBSL engineering design unit contribute to middle school students' sense of purpose in life and their perceptions of and interests or aspirations in engineering?
2. What features and instructional priorities did the educators (teachers and mentors) perceive as being important to facilitating a K–12 PBSL engineering design unit, especially with regard to promoting youth purpose and interest in engineering?
3. What are some initial guiding principles for the design and enactment of K–12 PBSL engineering design units?

Research Setting and Context

School

This research primarily took place during the 2019–2020 academic year in a sixth-grade class at a private Catholic school in Central Texas. It should be noted that while all of the enactment of the unit and survey distribution occurred before the March 2020 onset of the COVID-19 pandemic in the United States, the follow-up interviews were completed virtually because of the national and local pandemic-mitigation strategies, such as social distancing and stay-at-home orders. The school was a parochial school affiliated with the Diocesan Catholic Church with which it shares its property. The school served students from three years old to 13 or 14 years old, offering an Early Childhood and Development Center (ECDC), a pre-kindergarten Montessori program, and a kindergarten through eighth grade elementary/middle school program. Students attending the school came from families that are registered parishioners of the eponymous parish church, from neighboring parishes, or from elsewhere in the Central Texas area. As such, the school served a population of local and commuting students.

The school offered one class per grade level for kindergarten through eighth grades. The sixth through eighth grade classes followed a departmentalized and team-teaching model of instruction, with teachers who specialized in teaching one to two subjects across two or more grade levels (Parker et al., 2017). It also offered a variety of standard curricular and extracurricular elective programs and amenities including: a band program, a visual arts program, afterschool sports, a robotics club, a Makerspace, and a library, among other similar offerings. During the time of this research however, the library and Makerspace were undergoing a major renovation and update and were thus inaccessible to students for several months during the academic year, including throughout the sixth graders' PBSL engineering design unit.

Course Context

Courses

The PBSL engineering design challenge unit (hereafter referred to as "the PBSL engineering unit," or the "PBSL unit," or simply, "the unit") occurred primarily within the sixth grade science course during the Fall 2019 semester and concluded early in the Spring 2020 semester. The science curriculum followed the sixth-grade state standards, known as the Texas Essential Knowledge and Skills (TEKS). At the beginning of the unit, some of the lessons also occurred within the sixth-grade Religion in Action (RIA) course, a bi-weekly, core, faith-based course that the sixth-grade science teacher also taught. The main objective of the RIA course was to cultivate principles that encourage the application of Catholic doctrine and theology in students' lives through discussions of lived experiences of the Catholic life. The decision to integrate some of the early lessons of the PBSL engineering unit into the RIA course and aligning it with the diocese's religious education standards emerged during a planning meeting with the teacher prior to the start of the PBSL engineering unit. During this meeting, it became apparent that one especially relevant aspect of the RIA course was Catholic Social Teaching principles, which paralleled with the underlying principles of the service-learning philosophy. The teacher and I thus mutually decided to integrate some of the lessons that specifically discussed service-learning into this course so as to cultivate a cross-disciplinary approach to the PBSL engineering unit. The details regarding the specific lesson themes, activities, and sequence are explained in an ensuing section in this chapter.

Course Schedule

The sixth-grade science class occurred daily. However, the minutes allotted to the course varied through the week: on Mondays and Fridays, the science class met for 45 minutes from 10:00am to 10:45am, while on Tuesdays, Wednesdays, and Thursdays, the science class met for about 80 minutes from 7:45am to 9:05am. The Religion in Action course only met twice a week, on Mondays and Fridays for about 45 minutes from 12:45 pm to 1:30 pm. However, we (the teacher and I) did not teach the PBSL engineering unit every day or during every science or RIA class session throughout the unit. Rather, we taught the unit intermittently throughout the Fall 2019 and early Spring 2020 semesters so as to ensure that students were still learning other aspects of the science curriculum; we maintained student engagement; and we accommodated the teacher's, the class's, and my scheduling constraints, respectively. Furthermore, the number of days in the week devoted to the PBSL unit was also dependent on and responsive to student progress as they worked through the various components of the unit and each phase of the engineering design process (EDP). That is, while some components or phases required more time, taking about four to five consecutive class periods, other phases required fewer sessions (two to three class periods) that were distributed across multiple weeks. Typically, however, about two to three science class periods a week were devoted to the PBSL engineering unit.

Class Composition

Teacher

The sixth-grade science teacher, hereafter referred to by the pseudonym "Mrs. Daley," was a veteran teacher at the school, and had taught at the school for eight out of her 13 years of teaching. During the 2019–2020 academic year, her teaching assignment consisted of sixth-grade homeroom, sixth-grade science, sixth-grade on-level math, sixth-grade Religion In Action, fifth-grade science, and fifth-grade math. Prior to this, she taught first-grade as a self-contained teacher. Mrs. Daley holds a bachelor's degree in social work and a master's degree in education. Mrs. Daley chose to collaborate with me to implement the PBSL engineering project with her sixth-grade class because she wanted to grow in her understanding and teaching of engineering and project-based learning. Furthermore, in an effort to promote best teaching practices, the school principal had required teachers to implement at least one project-based learning unit within their courses or classes; thus Mrs. Daley was interested in this collaboration because it would further help her meet that goal. She had also expressed a general desire to improve her science teaching abilities, of which she felt less confident than her math teaching abilities.

Students

There were 24 students in the sixth-grade class. The class was evenly split by gender, with 12 male students and 12 female students. This allowed for an initial division of the class into six design teams of four students (two male students and two female students per team). However, partway through the fall semester, one male student unenrolled from the school, leaving one team short one member. Given the option, that team chose to disband and redistribute themselves into the other existing teams rather than continue as a team of three. In January 2020, a new male student joined the class, and the teacher assigned him to one of the existing design teams since all teams were far enough into the design process that it would have been more disruptive to reassign group members for equal team sizes. Thus, ultimately, there were five design teams, with four teams of five and one team of four.

Researcher's Positionality

To better contextualize the design experiment of the PBSL engineering design unit at the center of this research, it is important to disclose my own positionality as the participant-researcher in relation to this project. While I had been a long-time and regular member of the parish church affiliated with the school, my collaboration with the school did not begin until several years after I first joined the parish. I was invited by the superintendent and assistant superintendent of the local Diocese of Catholic Schools to present at the diocese-wide annual faculty professional development day in the fall of 2018, which was hosted at the school. There, I had my first introduction to the school principal, who at the end of the spring 2019 semester, approached me about the prospect of collaborating with some of the middle school science teachers to develop a project-based service-learning engineering/STEM unit. The school principal espoused and prioritized project-based learning and was committed to fostering it throughout the school. She subsequently invited me to the school, where I had the opportunity to first meet Mrs. Daley, and we mutually agreed to pursue a collaboration during the 2019–2020 academic year.

It is also important to note that, given that the school was a parochial Catholic school, my positionality as a baptized, practicing Catholic and former Catholic school teacher afforded me important background knowledge and cultural competence to initially access and work intimately within such a setting. Furthermore, as noted earlier, I (coincidentally) had long been a parishioner at the church, which afforded me further familiarity with the church and school community and their collective mission. I did not receive, request, or desire any monetary compensation during my collaboration with the school. Neither did I offer nor provide any monetary compensation or incentives for the collaboration. The collaboration was entirely voluntary and mutually desired by both parties (the school and myself).

The PBSL Engineering Design Challenge Unit

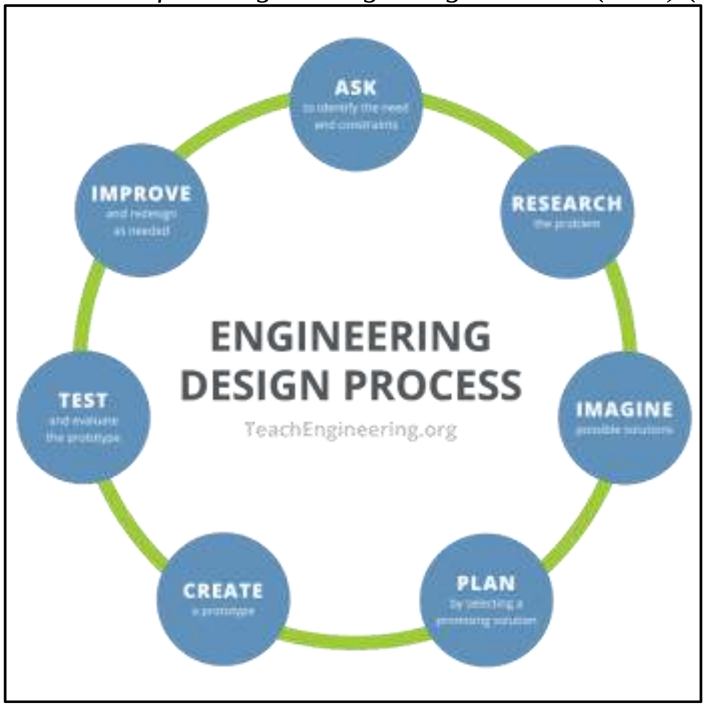
Curriculum Design and Planning

The development of the project-based service-learning unit was, in many ways, dynamic in its unfolding. It was grounded on the core principles of service-learning and project-based learning, as well as the goals for K–12 engineering, as previously discussed in Chapter Two. In planning and designing it, Mrs. Daley and I especially aimed to centralize student interests and societal concerns while also being cognizant of what would be realistic within the constraints of time, resources, and developmental appropriateness. As such, we often developed the lessons in response to student needs, interests, curriculum constraints, and the time and resources available to us. Mrs. Daley and I would meet regularly—nearly once a week— to plan the coming week's lessons for the unit. As a starting point, we referred to and adapted some of the lessons from Purdue University's EPICS (Engineering Projects in Community Service) K–12 Program's *Updated Condensed EPICS Design Curriculum* (2017) and the *EPICS K–12 Middle School Engineering Design* curriculum modules (2015), both of which are freely accessible on the EPICS K–12 online forum. However, we did not strictly follow the EPICS K–12 modules, but rather borrowed selected lessons and activities from the EPICS K–12 curriculum and synthesized them with our own lesson and activity ideas, along with other resources we found elsewhere. Mrs. Daley and I oriented the PBSL engineering unit around the state science and technology standards, especially as they pertained to scientific investigation, physical science concepts, and the design and use of technology as well as the diocese's religious education standards. These standards are summarized at the beginning of Table 3.1. However, the core structure of the unit was based on the engineering design process (EDP).

Although several versions and schematics of the EDP exist (Mosborg et al., 2005), we chose to use the EDP schematic published by The University of Colorado at Boulder's nonprofit initiative, TeachEngineering.org (often abbreviated to "TE") (TeachEngineering.org, 2020). This model of the Engineering Design Process features an iterative cycle consisting of seven primary stages: *ask*, wherein students scope and identify the problem to be solved as well as its constraints; *research*, wherein students learn more about the problem and existing solutions; *imagine*, which is the concept-generation phase of possible new solutions; *plan*, during which students select the best or most viable potential solution, define a timeline, acquire materials, and consider other logistical details in preparation to create their chosen solution; *create*, which is the building and prototyping phase; *test*, which is the phase where students test their prototypes and chosen solution against the previously identified design constraints; and *improve*, the phase in which students iterate and improve upon their prototype design based off the information derived from the testing phase (TeachEngineering.org, 2020). Figure 3.1 below presents the TE model of the engineering design process.

Figure 3.1

Schematic of the Engineering Design Process (EDP) (TeachEngineering.org, 2020)



Note. This version of the EDP was used to direct and discuss throughout and used to direct the PBSL engineering project.

Sequence

The PBSL engineering unit began toward the end of August 2019 and concluded at the end of February 2020. However, as noted previously, the unit was not taught continuously during this time, but rather occurred intermittently as an ongoing concurrent project throughout those seven months. Furthermore, the project came to a temporary "natural" pause toward the end of November, both due to the holiday season and a waiting period necessitated by the materials-procurement process. The ensuing paragraphs provide an abridged yet comprehensive account of the sequence of instruction and student activities that the PBSL engineering unit encompassed. The description of the unit's sequence is divided into the phases that more or less align with the key stages of the TeachEngineering (2020) conceptualization of the Engineering Design Process, though with a few additional phases, as are described below. Table 3.1, on the following three pages, summarizes the sequence by phases, their corresponding key lesson topics and activities, and approximate durations.

Introduction to Engineering. The project began with a few lessons focused on an introduction to engineering and the engineering design process. During these lessons, the main goals were to gauge students' preconceptions of engineering; to introduce engineering as the endeavor of applying scientific and mathematical principles to design solutions for problems in the world; and to introduce the engineering design process, with a particular emphasis placed on the latter of these. In addition to these discussions, the main learning activity was a mini-design challenge in which students were challenged to design a "wind mobile" using one sheet of paper, four straws, four life-savers candies, and any fraction of one yard of tape. Students had the chance to test their wind mobile designs and iterate upon it at least twice during the course of the challenge.

Table 3.1

Summary of PBSL Engineering Design Unit Sequence

STANDARDS ADDRESSED	
Standards Type/Source	**Relevant Standards**
Texas Essential Skills and Knowledge for Science-Grade 6 (Texas Essential Knowledge and Skills for Science, 2017)	(2) Scientific investigation and reasoning. The student uses scientific practices during laboratory and field investigations. The student is expected to: (A) plan and implement comparative and descriptive investigations by making observations, asking well defined questions, and using appropriate equipment and technology; (B) design and implement experimental investigations by making observations, asking well-defined questions, formulating testable hypotheses, and using appropriate equipment and technology; (3) Scientific investigation and reasoning. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions and knows the contributions of relevant scientists. The student is expected to: (A) analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, so as to encourage critical thinking by the student; (D) relate the impact of research on scientific thought and society, including the history of science and contributions of scientists as related to the content. (8) Force, motion, and energy. The student knows force and motion are related to potential and kinetic energy. The student is expected to: (A) compare and contrast potential and kinetic energy; (B) identify and describe the changes in position, direction, and speed of an object when acted upon by unbalanced forces; (C) calculate average speed using distance and time measurements; (E) investigate how inclined planes can be used to change the amount of force to move an object.

Table 3.1, *cont.*

Texas Essential Skills and Knowledge for Technology-Grade 6 (Texas Essential Knowledge and Skills for Technology Applications, 2012)	(1) Creativity and innovation. The student uses creative thinking and innovative processes to construct knowledge, generate new ideas, and create products. The student is expected to: (A) identify, create, and use files in various formats such as text, raster and vector graphics, video, and audio files; (B) create original works as a means of personal or group expression; (C) explore complex systems or issues using models, simulations, and new technologies to make predictions, modify input, and review results; and (D) discuss trends and possible outcomes. (2) Communication and collaboration. The student collaborates and communicates both locally and globally to reinforce and promote learning. The student is expected to: (A) participate in personal learning networks to collaborate with peers, experts, or others using digital tools such as blogs, wikis, audio/video communication, or other emerging technologies; (B) communicate effectively with multiple audiences using a variety of media and formats; and (3) Research and information fluency. The student acquires, analyzes, and manages content from digital resources. The student is expected to: (A) create a research plan to guide inquiry; (B) discuss and use various search strategies, including keyword(s) and Boolean operators; (C) select and evaluate various types of digital resources for accuracy and validity; and (D) process data and communicate results. (4) Critical thinking, problem solving, and decision making. The student makes informed decisions by applying critical-thinking and problem-solving skills. The student is expected to: (A) identify and define relevant problems and significant questions for investigation; (B) plan and manage activities to develop a solution, design a computer program, or complete a project; (C) collect and analyze data to identify solutions and make informed decisions; (D) use multiple processes and diverse perspectives to explore alternative solutions; (E) make informed decisions and support reasoning; and, (F) transfer current knowledge to the learning of newly encountered technologies. (6) Technology operations and concepts. The student demonstrates a thorough understanding of technology concepts, systems, and operations. The student is expected to: (I) discuss the relevance of technology as it applies to college and career readiness, life-long learning, and daily living;

Table 3.1, *cont.*

*Parish Religious Education Curriculum Sixth Grade** *The full title of these standards has been abridged to preserve the anonymity of the school site and the participants. Similarly, the full Reference citation is omitted from the references list because it contains revelatory information that would potentially compromise the anonymity of the school site.	REL-06.03.00. Goal 3 Christian Living: Understand and live the moral teachings of the Church through a life of discipleship REL-06.03.02. Explain that Christian living is the gift of active discipleship in Jesus Christ. Describe Christian living as following the teachings of Jesus Christ expressed through love of God and love for others, especially the poor. Identify the Two Great Commandments and the Beatitudes as teachings of Jesus. REL-06.03.08 Give the seven principles of Catholic Social Teachings. Define the seven principles of Catholic Social Teachings. Describe these principles and identify Biblical roots. REL-06.03.10 Relate how all have a responsibility to work for the common good of society. State the meaning of common good. Give examples of how to live life for the good of others. Give examples in the life and teachings of Jesus that show serving others generously. Make a list of people who work for the common good of society. REL-06.08.00 Goal 8 Parish Life: Understand and participate in the life of the Church as lived in the parish community such as, cultural aspects, worship, sacramental life, service, stewardship and missionary efforts. REL-06.08.01Relate that active involvement in the life of the Church is evident through different forms of participation in parish life. Identify forms of participation in parish life including attendance at Sunday Mass, sacramental participation, community participation and service to others. List ways that the parish invites its young members to participate in the life of the parish.

Phase	**Primary Lesson Topics and Key Activities**	**Key Activities and Guests**	**Approximate Length**
Introduction to engineering	• What is engineering? Who are engineers? What is engineered? • What is the difference between engineering and science? • What are design constraints? How do we test our designs?	• ***Mini design challenge (Focus: designing within constraints):*** In teams of 4, students designed and constructed wind mobiles out of paper, straws, and life saver candies	~1 week

Table 3.1, *cont.*

Phase	Primary Lesson Topics and Key Activities	Key Activities and Guests	Approximate Length
Introduction to service-learning	• What is service-learning? (EPICS K–12 Lesson) • Catholic Social Teaching–Overview of the 7 Principles • Examples of people who have served their community through learning and engineering: William Kamkwamba (the subject of *The Boy Who Harnessed the Wind*)	• ***Guest speaker:*** Parish Associate Pastor • ***Mini design challenge* (*Focus: Designing for someone else and their preferences and needs)*:** In different teams of 4, students designed an educational "tabletop" game for the 5th-grade students to play during a "free-exploration" period in their weekly schedule.	~1.25–1.5 weeks
"Ask" Part I- (Problem Identification)	• Different levels/types of community (family, school, church, neighborhood, city, state, country, global) • What are the needs in our community? • Creating an effective "Needs Assessment Survey"	• In different teams of 4, students drew a "level of community" to focus on and identified a specific person, department, or organization/institution that could benefit from their service-learning engineering project. Students then created a tailored "Needs Assessment Survey" and disseminated it to their chosen persons/organizations. After receiving the returned survey responses, the class voted to design a device to help some students' family members who suffered from arthritis.	~ 2 weeks

Table 3.1, *cont.*

Phase	Primary Lesson Topics and Key Activities	Key Activities and Guests	Approximate Length
"Research"	• Understanding arthritis (symptoms, causes, prevalence, challenges) • Exploring "prior art" (lesson inspired by EPICS K–12)	• ***Guest speaker:*** A student's parent who suffered with arthritis (Community Partner 1) • In different teams of 4, students generated questions to guide their background research, conducted some research on the web, and presented what they learned to the class in a brief 5-minute Google Slides-aided presentation.	~ 1–1.25 weeks
"Ask" Part II-(Problem Scoping)	• Defining the design challenge: What are we going to design for people with arthritis? • Identifying constraints	• The class developed a "project charter" (EPICS K–12 Lesson idea) to script their design challenge, identifying the main goals, constraints, and ideal timelines for the project.	~ 1 week
"Imagine" (Concept-Generation)	• Generating initial ideas for designs • Selecting a design out of many possible solutions	• In assigned teams of 4, students engaged in a "C-Sketch (Collaborative-Sketching)" idea-generation strategy. • Students attempted to render their team's selected designs using a free, cloud-based Computer-Aided Design (CAD) software, Tinkercad^{TM}, or to create multi-perspective manual sketches.	~2–3 class sessions
"Plan" Part I	• Initial prototyping to model the team's selected design, assess potential challenges, viability, etc. • Revising initial designs based on feedback	• Students constructed non-functional prototypes or models of their designs out of everyday objects or crafts to further envision their designs and tinker with functionality	~ 3–4 class sessions

Table 3.1, *cont.*

Phase	Primary Lesson Topics and Key Activities	Key Activities and Guests	Approximate Length
"Plan" Part II	• Basic foundational physical science concepts: Motors and gears • Identifying and budgeting for materials	• In their design teams, students compiled a Materials Request spreadsheet, wherein they identified desired materials and manufacturers and retailers selling these materials. Each design team had a budget of $120.	~ 1–1.25 weeks
"Create"	• Constructing functional prototypes	• In their design teams, students worked with a variety of tools and materials to construct, troubleshoot, and test a functional prototype of their team's design. • ***Key personnel:*** Adult mentors (expert engineers, hobbyist makers, and sewers)	~2 weeks
"Test" (and "Improve")	• Conducting multiple tests • Collecting data (observational and measurable, if possible) • Soliciting and reflecting on feedback from stakeholder/community partner • Improving or revising designs based on tests or feedback (iterating)	• In their design teams, students determined the appropriate tests for their designs. They recorded data as observational notes and descriptive quantitative data • A community member diagnosed with arthritis visited the class, tested each design and gave students verbal feedback on their designs.	~2–3 class sessions (concurrent/ embedded within the 2 weeks devoted to the "Create" phase)

Table 3.1, *cont.*

Phase	Primary Lesson Topics and Key Activities	Key Activities and Guests	Approximate Length
Presentations	• "Final" presentations and demonstration of each team's functional prototypes • Reflecting on their Engineering Design Process • Communicating about their work and presenting a professional presentation	• Students prepared and presented a "final" design presentation for an authentic audience consisting of some of their parents, the school principal, the assistant superintendent, the expert engineering mentors, the pastor, and one of the community service partners. Presentations were in a gallery-walk style so as to allow students to demonstrate their designs more easily and to facilitate dynamic interactions between students and their audience members.	~ 1 week of preparation; 1 class session for final design presentations

Introduction to Service-Learning. Around the same time we began the *Introduction to Engineering* lesson sequence, we also began to introduce the notion of service-learning in the Religion in Action course, as well as the seven principles of Catholic Social Teaching (life and dignity of the human person; call to family, community, and participation; rights and responsibilities; option for the poor and vulnerable; dignity of work and rights of the workers; care for God's creation; and solidarity) (United States Conference of Catholic Bishops, 2005). The following week, we continued the conversations around service-learning, namely the intersection of engineering and service-learning in the science course. A central theme of these discussions were examples of youth, like William Kamkwamba (Kamkwamba & Mealer, 2010), who have engineered solutions and innovations in response to problems within their own communities. Students then participated in another mini-design challenge in which they were tasked with designing a tabletop arcade/board game for the fifth-grade class to play during their weekly free periods. A key component of this challenge was an interview with their "clients" (the fifth graders and their teacher) in which the sixth-grade students were to ascertain their clients' requirements and preferences and incorporate their clients' desires into their tabletop designs. The aim of this challenge was to introduce, in a low-stakes context, the notion of designing for someone else as opposed to designing for oneself.

"Ask" Part I—Problem Identification. After these introductory lessons, the focus of the unit then shifted toward identifying a community problem to anchor the main PBSL engineering design challenge. This initial problem-scoping sequence began with a conversation about some potential "levels" of community (in relation to the student as self), namely: family, school (and/or church), neighborhood, city, state, country, and the world. As the list order may indicate, Mrs. Daley and I chose to present this hierarchical conceptualization of community for two reasons. Firstly, we wanted to inherently illustrate that community can be considered in micro and macro terms; secondly, parsing the notion of community in this way allowed us to more easily scaffold students into the subsequent "Needs Assessment" activity that was the central task for this initial problem-scoping phase.

In this activity, students worked in teams of four to identify a potential community member within their group's assigned community level, and to design a "Needs Assessment Survey" (EPICS K–12, 2015) for that community member. Given that there were six groups, students identified the following six community members or organizations to survey (the corresponding community levels are noted in parentheses): grandparents/parents diagnosed with arthritis (family); school cafeteria coordinator (school); community garden (church); the local fire station (neighborhood); the city's humane society (city); and a children's home organization (state). Each group then drafted and revised a tailored Needs Assessment Survey using either Google Docs or Google Form and disseminated these surveys to the respective identified community members via email. After receiving responses from four out of the six targeted community members, we had a class discussion to narrow our options and select a project we would be able to reasonably undertake while still allowing students to design something novel. This discussion concluded with a vote between two projects: helping family members with arthritis, or designing signs for the church's community garden. The class settled on the first of these, and thus designing an assistive device to help arthritis patients with daily tasks became the anchor design challenge for the unit.

"Research." Students then commenced the "Research" phase, in which their primary aim was to learn more about arthritis as well as existing innovations on the market that are designed to assist arthritis patients. Working in different groups of four, students generated questions using a Know-Want to Know-Learned (K-W-L) chart (Ogle, 1986), which then served as the guiding questions for their web-based research. During this phase, Mrs. Daley and I also invited one student's father, Mr. Yapan (pseudonym), who was diagnosed with arthritis, to speak about his struggles with his condition. As a class, students pre-scripted a set of questions to ask Mr. Yapan, especially focusing on what his requirements and preferences would be for an assistive device. Mr. Yapan's guest-talk was a pivotal point in the unit sequence because this was the first interaction students had with the target "service/community partner," or client, for their service-learning design challenge. It also set the foundation for the next key phase, which was, in essence, a second problem-identification phase ("Ask/Problem Identification II" in Table 3.1).

"Ask" Part II—Problem Scoping. As opposed to the first problem-identification phase, this second problem-identification phase focused on defining the problem more specifically and identifying the design constraints. After we heard and reflected on Mr. Yapan's talk, I led the class in developing and completing the project planning charter document. The project planning charter activity and template came from the EPICS K–12 curricula (2015; 2017), and it was intended to serve as the definitional, anchoring document for the service-learning design challenge. It prompted students to consider and define the problem and its constraints, the various stakeholders in the design challenge, the community profile, prior innovations, and the outcomes, deliverables, and timeline for their project. To scaffold students into thinking about these various aspects of the project, I primarily had students focus on defining their design challenge by prompting them to more specifically articulate the end-functions of their designs, the various constraints and preferences—keeping in mind those articulated by Mr. Yapan, in particular—and the outcomes and deliverables they aimed for, as well as a general timeline. While we did have class discussions as to the other aspects of the project charter, in the interest of conserving time and maintaining realistic expectations, I scribed the class's collective ideas and subsequently drafted the other components of the project charter (such as: the statement of purpose; the community partner and community profiles, stakeholder basic requirements; stakeholder and stakeholder requirements; identifying existing projects or programs). Figure 3.2 depicts an excerpt of the class's project charter, specifically the "Outcomes and Deliverables" section, which in essence encompasses the class's design challenge statement.

Students' final designs diverged, to varying degrees, from their stated design challenge goals, as discussed later in this chapter. Nevertheless, Mrs. Daley and I felt it was important that students had some ownership over the design challenge statement for at least two major reasons. First, given that students had identified and selected this particular population to serve through their engineering challenge, it seemed appropriate that they had some input in defining the scope of their challenge. Secondly, in crafting their own design statement, students had the opportunity to more actively engage in the exercise of problem identification and scoping.

Figure 3.2

Excerpt from Sixth-Grade Class Project Charter

Outcomes and or deliverables: *What are you hoping to accomplish with this project, this would include addressing the goals and any constraints that you have identified.* We are trying to build a product that helps people with arthritis. More specifically, this device will help people with arthritis open things and twist like jars and door knobs. The device must: • Move (bend or turn) in at least two types of direction as a healthy wrist can move • Be handheld • Must be able to help open or twist multiple objects and must be multifunctional • Must be cleanable (preferably machine washable) • Lightweight • Cost-effective (budget: $120/team) • Portable Preferences (but not required): • Device can rotate in all 360 degrees to allow greater flexibility of opening devices. • at least 60% eco-friendly (recycled materials; biodegradable)	**What are the immediate expectations for the project?** Immediately we want a functioning prototype that meets the requirements stated on the left. • We would like to have a functioning prototype by mid to late January. • We will do at least two tests and revisions before getting our clients'/community partner's feedback. • We will have our community partner identify which prototype will be potentially most useful or appealing to them *What are the long-range expectations for the project?* The long range expectations for the project include opportunities for optimization, re-iteration, and hopefully, creating a usable device.

Note. The "Outcomes and or deliverables" section encompasses the students' design challenge statement in that it articulates their stated goals for the type of assistive device they wanted to create for their family members struggling with arthritis.

"Imagine" (Concept-Generation). Having more concretely defined their design challenge, students then progressed to the "Imagine" phase, or the concept generation phase. Until this point, students had worked in fluid groups of four, with varying configurations, throughout the previous stages. However, before starting the "Imagine" phase, Mrs. Daley and I assigned students into six design teams of four (though later, with the departure of one student, one group redistributed themselves into the remaining five groups). We opted to assign design teams at this point in an effort to foster more optimal team dynamics and approximate more equitable teaming, particularly because this phase marked the point in which more static design teams would become necessary for the sake of continuity and the realization of each team's chosen design. To facilitate their concept generations, we utilized the Collaborative-Sketch (C-Sketch) strategy espoused by Shah et al. (2001). C-Sketching is an "intuitive" idea-generation method in which each student designer (student A) within the design team sketches an initial idea, and passes it along to the next team member (student B), who then modifies without completely erasing the original design. However, modifications must be done graphically and without verbal communication between team members. Each design is then passed to the next team member (student C) for modification, and so forth, until each design is rotated through the entire group so that each member modifies each other member's design (Shah et al., 2001). After students engaged in the C-Sketching activity, each team then discussed and selected a concept they wanted to pursue. Upon arriving at a consensus for a viable, potential design, students then worked in their teams to attempt either a 3D computer-aided design (CAD) rendition of their team's design using Autodesk's free, cloud-based platform Tinkercad, or a multi-perspective manual sketch of the design.

"Plan"–Part I. With each team having identified a concept, students then moved to the "Plan" phase. This phase consisted of two major aspects of planning: "Plan Part I" phase and a "Plan Part II" phase. In the Plan Part I phase, the primary aim was to give students the opportunity to more concretely conceptualize their selected design idea by having them model it. Students constructed an initial prototype (what we referred to as "the proxy prototypes" in class) out of everyday craft or recyclable materials. In so doing, we wanted to encourage students to tinker with and model their devices to get a sense of what component parts they may need and to think about how the parts might work together. Students were given a little under a week to construct these initial prototypes. Afterwards, each time had the opportunity to improve upon their sketches or renditions. During this time, I also solicited external feedback from college engineering students of The University of Texas at Austin's (UT-Austin) Student Engineers Educating Kids (SEEK) student organization, as well as professional "makers," to comment on each team's sketch and provide students with additional ideas or advice that might scaffold the construction of their functional prototypes at the end of the project.

“Plan”—Part II. After students had the opportunity to model their ideas with common items and consider the feedback they received from the undergraduate engineers and adult “makers,” students then entered into the “Plan Part II” phase. One primary objective of this phase was to have students try to identify some of the scientific principles or concepts that they might need to apply or better understand to facilitate the construction of their designs. In groups, students used a K-W-L chart to generate questions about scientific principles they needed to apply or learn more about. In an attempt to anticipate some of the common scientific concepts or principles that seemed potentially applicable across all the teams’ designs, Mrs. Daley and I led students in two one-period, hands-on lessons on motors and gears. However, as the “Create” phase demonstrated, the use of motors and gears proved either unnecessary or too challenging to incorporate within the constraints of the students’ available time, equipment, and conceptual understanding.

The second primary objective was to create a materials purchase order. The school principal had generously approved a portion of the teacher’s remaining textbook budget to be used for purchasing materials for this project, which allowed a budget of $120 per team (though most teams stayed well under this budget). As the name implies, the materials purchase order task required students to identify and plan for the procurement of materials needed to construct their devices. Each team completed a spreadsheet that identified the items requested, the vendors, the costs, and a rationale for each purchase. Mrs. Daley then submitted these spreadsheets to the school’s accounting personnel, who facilitated and coordinated the ordering. At this point, the project hit a sort-of natural break in the unit, in that progress into the next phase, the “Create” phase, was contingent upon the receipt of the ordered materials. Furthermore, the completion of this “Plan II” phase fell around the time of the end-of-the-year holiday season, which also meant a number of school-wide holiday festivities and celebrations. Thus, in an effort to honor these celebrations and to maximize a sense of continuity, Mrs. Daley and I decided it would be better to resume the project after the school's winter break.

"Create." During the two weeks after winter break, several of the students' requested items arrived, and thus students were ready to begin the "Create" phase the following week. This phase lasted about two weeks, beginning in the last week of January and ending in the first week of February. In this phase, the primary aim for each design team was to construct a functional prototype of their conceptual designs. Of course, during this phase, students inevitably modified and iterated upon their original concepts, or innovated with new design features or mechanisms as they encountered various challenges or constraints during their building process.

It is important to note that some key players during the "Create" phase were the adult mentors who volunteered to help guide students as they attempted to construct their designs. Before beginning this phase, Mrs. Daley and I circulated requests within our respective networks for expert engineers, makers, or other willing adults to volunteer some time to mentor students during the creation/building phase. We ultimately had five adults who volunteered to mentor students, including a retired mechanical engineer, a biomedical engineer (who held a Ph.D. in biomedical engineering), a doctoral candidate in mechanical engineering, a hobbyist maker (one of the student's parents), and a hobbyist sewer (another faculty member of the school). The first three adult volunteers each chose to come in for at least four out of the approximately eight class periods devoted to the building and construction of devices, though some of them volunteered to come in for even more of class sessions. The latter two adult mentors were a little more constrained because of their work schedules, but still volunteered time for at least two to three class periods. At least three of the mentors also volunteered to lend some tools and supplies to students.

The adult mentors offered guidance on multiple aspects of the students' construction processes, including advice on ways to achieve a certain construction goals, such as tool-selection and techniques; suggestions of possible ways to troubleshoot or other alternate solutions to consider; safety instructions and additional supervision; and, if needed, help with the actual manipulation of construction materials. It should be noted that, with the exception of safety precautions or considerations, Mrs. Daley and I strongly encouraged mentors to avoid "taking over" student projects and to guide and advise students regarding design decisions, as opposed to controlling decisions, even if student ideas were not likely to succeed. We also encouraged mentors to engage students in reasoning discussions when making design decisions or constraints and to share their expert knowledge when occasions arose for it. In large part, all five of the mentors abided by these guidelines and collectively prioritized students' agency and ownership during this creation phase.

The invitation of the mentors also afforded some additional opportunities for spontaneous discussions around the nature of engineering and the work of engineers. Of their own accord, each of the three mentors asked Mrs. Daley permission to give the class a brief informal presentation about their own work, projects, or engineering thinking heuristics or frameworks. For example, the professional biomedical engineer, Dr. Donne (pseudonym), volunteered to bring in bio-compatible 3D-printed components of custom-made orthopedic implants (made for patients with orthopedic conditions), which his firm produces. At the start of one class session, he gave students a brief explanation of how these components are designed and produced, highlighting how the class' own assistive-device challenge is similar to the type of work done by professional biomedical engineers in his industry.

“Test” (and Improve). During the two weeks of constructing their designs, each team had a functional assistive device, or at least functional prototype. Students then progressed to the “Test/Improve” phase, in which they were tasked with testing their devices and evaluating them according to their design statements. Much of the testing and improving process happened dynamically, in that much of it occurred during the two weeks that students constructed their devices and tested certain functionalities as they constructed. However, once teams had come close to completing their iterations, they were encouraged to test their devices in a more systematic sense.

Given that each team’s design was unique and differed in functionality from each other’s, it was difficult for each team to perform the same tests. Indeed, it became markedly apparent that several teams’ designs and iterations throughout the “Create” phase diverged at least slightly from the original criteria listed in their project charter, but all teams nevertheless created a type of assistive device for arthritis patients. As such, each team tested their own devices as per the functions that their devices were constructed to perform. However, to encourage students to evaluate their designs against the original design statement goals, Mrs. Daley and I additionally required students to test their devices’ ability to open or close various jars and bottles of different sizes.

Aside from their self-led testing, another key event in this phase was the evaluation of student prototypes by a service partner, a community member diagnosed with arthritis. One of the adult mentors, Mr. Humberto (pseudonym), a retired mechanical engineer, noted that his elderly sister suffered from arthritis. He and Mrs. Daley thus invited his sister to come visit the class to test each team’s design and provide them feedback. As they demonstrated and presented their functional prototypes to the service partner, students were instructed to take notes on her comments and feedback. Students were then allowed to make minor improvements or modifications based on the feedback they received from the service partner. Students were also encouraged to reflect and write about what other improvements or modifications they would like to make, if they had more time and resources available to them.

Presentations. The unit concluded with the class presenting their functional prototypes. These presentations occurred over one class period and were semipublic in that Mrs. Daley and I invited members of the school community, including the assistant superintendent of the local Diocese of Catholic Schools, the school principal, the parish pastor, students' parents, and the mentors as well as the service-partners to attend the student presentations. To facilitate dialogue, design-demonstration presentations occurred in a "Gallery Walk" format, wherein each team presented concurrently as various audience members circulated the room. This allowed each team to demonstrate their prototypes and interact with audience members in a more dynamic fashion during a limited time frame. Aside from giving students an opportunity present their designs to an authentic audience, one of the primary objectives of the final presentations was to encourage students to reflect on their design process. To guide their reflection and presentations, Mrs. Daley and I provided students with a number of reflection questions pertaining to each stage of the engineering design process; students were required to incorporate their responses to at least three questions for each phase within their group's presentation. Students had about one week to draft, revise, and rehearse their presentations before the final presentations occurred at the end of February 2020.

Data Sources and Participants

In all, there were 17 (n=17) participants, including students, the teacher, and the professional engineering mentors, who participated in the post-unit data collection measures.

Twelve students completed the survey described above, while 13 students participated in the student interviews. Eleven students chose not to participate in either the post-unit survey or the post-unit interviews. Likewise, the one teacher (Mrs. Daley) and three professional engineering mentors (Dr. Donne, Mr. Aldred, and Mr. Humberto) participated in individual post-unit interviews. Table 3.2 provides the demographic profiles of each student and educator (teacher and mentors). The ensuing paragraphs in this section also describe and explain each data source and corresponding participants. Briefly, data sources included a post-unit survey for students; respective interview protocols for the students, teacher, and mentors; and artifacts collected from the unit.

Table 3.2

Demographic Profiles of Interview Participants

Participant Type	Pseudonym	Gender	Age Range	Race/Ethnicity	Miscellaneous Notes
Student	Alan	Male	11–12 yrs old	Hispanic/Latino	[redacted]
Student	Anastasia	Female	11–12 yrs old	Mixed Race/Ethnicities	
Student	Ophelia	Female	11–12 yrs old	White	
Student	Yohan	Male	11–12 yrs old	White	
Student	Ethan	Male	11–12 yrs old	Mixed Race/Ethnicities	
Student	Ivy	Female	11–12 yrs old	White	
Student	Oscar	Male	11–12 yrs old	Hispanic/Latino	
Student	Allie	Female	11–12 yrs old	Mixed Race/Ethnicities	
Student	William	Male	11–12 yrs old	Other	
Student	Elijah	Male	11–12 yrs old	White	
Student	Iliana	Female	11–12 yrs old	Hispanic/Latina	
Student	Ezra	Male	11–12 yrs old	White	
Teacher	Mrs. Daley	Female	35-40 yrs old	White	Bachelor’s degree in Social Work; Master’s degree in Education
Mentor	Dr. Donne	Male	30–40 yrs old	White	Ph.D. in Biomedical Engineering
Mentor	Mr. Humberto	Male	60–70 yrs old	Hispanic/Latino	Retired Mechanical Engineer
Mentor	Mr. Aldred	Male	30–35 yrs old	White	Ph.D. Candidate in Mechanical Engineering

Survey Instruments

The survey instrument aimed to gauge students’ potential sense of purpose in life, their attitudes toward their experiences with the project-based service-learning engineering unit, and their interests and aspirations in future STEM (especially, engineering) learning and careers. It was administered a week after students completed their final design presentations and the unit had concluded. The survey consisted of 28 items that were divided among four parts. The first part measured students' purpose-in-life; the second part surveyed students' attitudes and views regarding the project-based service-learning engineering design unit they just completed; the third part measured students' interests and aspirations in future STEM learning or STEM careers; and the fourth part asked students for relevant personal and demographic data.

The first part of the survey included 16 items. Twelve of these items were five-point, Likert-type items from the "The Claremont Purpose Scale (CPS)," a validated purpose scale developed by Bronk, Riches, and Mangan (2018). The CPS was especially designed and developed to measure youth purpose and measures the three major dimensions of purpose: meaningfulness, goal-orientation, and the beyond-the-self dimension (Bronk et al., 2018). It has high internal consistency with α = .917–.945, as well as construct and convergent validity when compared with other validated and frequently used purpose scales.

The other four items in this portion of the survey were borrowed from a measure obtained from Stanford University's Center on Adolescence that is also meant to assess youth purpose. At the time, it was the most recent iteration of a previous instrument developed by the center, the "Revised Youth Purpose Survey" (Bronk, 2014). This version of the scale, yet to be titled, was in development and undergoing the validation process (H. Malin, personal communication, November 22, 2019). The four items borrowed from this measure included a matrix-like item that contained 18 sub-statements that each described a life goal. All 18 statements had seven Likert-type responses ranging from "Not at all important to me" to "Essential or Extremely important to me."

The next two items, borrowed from the Stanford instrument, were open-ended responses that asked students to describe one personally meaningful goal he/she may have and *why* he/she wanted to accomplish that goal. The final item in this section was another matrix-like item of nine sub-statements asked students to indicate on a five-point, Likert-type scale their agreement or disagreement with each sub-statement as it pertained to the goal they described in the previous two items.

The second part of the survey consisted of three items designed specifically for this study. It aimed to gauge students' perceptions of the PBSL engineering unit and how it may have impacted their interests and aspirations to study or pursue a career in engineering in the future. The first item was a matrix item consisting of five sub-statements that asked students to indicate on a five-point, Likert-type scale how meaningful various aspects of the PBSL engineering unit, engineering, or community service was to them. The other two items were also five-point, Likert-type items measuring the likelihood of students studying engineering or pursuing an engineering career in the future as a result of participating in the PBSL engineering project.

The third portion of the survey measured students' engineering interests and career aspirations. It consisted of three matrix items. The first two items in this section were adapted from the Academic Pathways of People Learning Engineering Survey (APPLES), which is a psychometrically validated instrument designed for undergraduate engineering students and which measures various constructs, such as skills, identity, education, and workplace environment, that may predict engineering career trajectories (Sheppard et al., 2010). It has a moderate to high internal consistency measuring motivation, with Cronbach α = .72–.83 for this construct.

The first matrix item, based on a similar matrix item from the APPLES survey comprised of three sub-statements, asked students to indicate their certainty on a five-point, Likert-type scale of their plans to study engineering in the future or in college, and their plans to be an engineer. The next matrix item was borrowed directly from the APPLES instrument (Sheppard et al., 2010) and provided 16 statements that described reasons students might be interested in becoming an engineer in the future. Students indicated how much of a reason each statement corresponded with their desire to be (or not be) an engineer on a five-point Likert-type scale.

The final matrix item was adapted from the STEM-Career Interest Survey (STEM-CIS) survey (Kier et al., 2014). This matrix item listed 13 "I"-statements about the student's perceived ability, interests, or beliefs within the four STEM disciplines. For example, one statement read, "I am able to get a good grade in my science class." Four of these statements described a personal ability or belief about himself/herself in Science, another four with similar sentence stems posed statements about himself/herself pertaining to Math, and another four related to technology. Given that some of the engineering statements were either not applicable, and because similar information was captured by other items throughout the full survey, only one statement regarding engineering (i.e. "I am good at engineering") was included in this item to avoid redundancy and to reduce the length of the survey. This matrix item was set to a seven-point, Likert-type response scale indicating level of agreement.

The final, demographic part of the survey consisted of five required items and one optional item. The first three items in this section were open-response items asking each student to identify their name, school, and grade for follow-up interview purposes. Two other items had multiple-choice responses pertaining to gender and race/ethnicity. The final, optional item was an open-response item that gave students the opportunity to share anything else they wanted to share regarding their purpose in life and/or values, their experiences doing a PBSL engineering project, or their future career interests. The complete survey instrument used in this study can be found in Appendix A at the end of this document.

The rationale for this survey design was to gauge students' perceptions, attitudes, and interests across the three constructs at the center of this inquiry: purpose-in-life, engineering/STEM career-interest, and project-based service-learning. Incorporating these three constructs within the same survey allowed me to gain a baseline understanding of the students' views of the project-based service-learning engineering unit, their purpose-development status, and their interests and aspirations regarding engineering.

Survey Participants

Of the 24 students in the sixth-grade class, 13 students returned parent consent and student assent forms agreeing to participate in the survey and interview study following the completion of the PBSL engineering unit. Twelve of these students completed the survey, with five of these respondents being female and the remaining seven male. Five of the student respondents identified as "White," three as "Hispanic/LatinX," three others identified as "mixed-race/ethnicities," and one student selected the "other" response for the race/ethnicity item.

Interview Protocol

To more thoroughly understand the perspectives of key stakeholders within the PBSL engineering unit, I conducted interviews with participating students, the teacher, and mentors. The interviews were semi-structured, and for each type of stakeholder, there was a separate interview protocol tailored to the participant's respective role. However, all three protocols shared similarities in the constructs and topics discussed. For all three protocols, I focused on drawing out the participant's perspectives as they related to their general and personal sense of purpose in life, notions of engineering, and perspectives on the project-based service-learning engineering design unit.

The interview protocol for students paralleled the post-unit survey in that it consisted of questions that gauged their sense of purpose in life or purposeful inclinations; their perceptions regarding the PBSL engineering project, including their perceived learning; and their notions of, interests in, and aspirations in engineering. It should be stated, however, that while the interviews with all 13 participating students maintained this triadic focus, I amended the interview protocol a few times for the sake of clarity and to more effectively gauge students' thoughts as they pertained to certain constructs. For example, after the ninth interview, I added a prompt which asked, *"When I say the words 'purpose*-in-*life,' what does that phrase mean to you?"* before directly asking students questions regarding their own sense of purpose in life. After noticing that several students seemed to consistently struggle or needed clarification with these questions, it became apparent that a question that first gauged how well students understood the notion of purpose in life was necessary.

Other emergent questions that I added to the protocol asked students about other past or current community-service involvement and engineering experiences or exposure. I added this question to acquire a better sense of a student's potential prior or existing proclivities toward service or socially purposeful activities. Finally, for each student that completed the survey, I also asked a few follow-up questions to their responses on various items from the survey. Generally, these survey follow-up questions focused on those items asking students about their life goals, the personal meaningfulness of the PBSL project, and the various reasons for potential interests in a future engineering career. The student interviews occurred online about 1.5 months after the conclusion of the unit. The duration of the student interviews ranged between approximately 30 and 60 minutes.

The interview protocol for the participating teacher, Mrs. Daley, also aimed to elicit reflections and perspectives about her experiences about negotiating the planning and implementation of the unit. In particular, the protocol was designed to elicit responses respective to her sense of self-efficacy in teaching engineering and implementing a project-based service-learning pedagogy before, during, and after the project; her reflections on pedagogical strategies, curriculum design principles, and challenges with enacting the unit; and her perceptions as to how the unit impacted student learning. Similarly, for the mentors, the interview protocol focused on their perspectives and insights about mentoring; messaging about authentic engineering and how to engage students in classroom projects that convey those messages; and strategies to foster effective mentorship partnerships and experiences. The full interview protocols for the students (the amended version), teacher, and mentors can be found in Appendices B, C, and D, respectively.

Interview Participants

The interview portion of this study consisted of three groups of participants: students, teachers, and the engineer mentors. The student interview participants consisted of all 13 assenting students (12 of whom completed the survey) described above and whose parents provided consent forms. Further details of each student interview participant are summarized in Table 3.2. In addition to the student interviews, the teacher, Mrs. Daley, also agreed participate in an interview after the completion of the PBSL unit.

Of the five mentors who helped students during the creating and prototyping phase, three mentors agreed to participate in interviews. All three mentors were male and had professional expertise in engineering. The first mentor, Dr. Donne, had earned a Ph.D. in biomedical engineering and worked for an engineering firm specializing in the development of osteo-prosthetics, especially using 3D-printers. Dr. Donne had a daughter enrolled in the kindergarten class at the school and decided to help with the sixth-graders' project after an email request that Mrs. Daley sent to the schoolwide parent listserv. The second mentor, Mr. Humberto, was a retired mechanical engineer. He was a longtime parishioner of the church and also frequently served as a substitute teacher at the school. He used to help with a local engineering outreach program that sought to promote engineering interest among K–12 students. He also came to learn about the sixth-grade PBSL engineering project from Mrs. Daley, for whom he had occasionally substituted, as well as through conversation with me. The third mentor, Mr. Aldred was, at the time, a Ph.D. candidate in mechanical engineering at an institution in Central Texas. He was a personal acquaintance of mine and came to learn about the project from me; he was very willing to oblige my request to come help students during the prototyping and building phase.

Artifacts

At the conclusion of the project-based service-learning engineering unit, a number of student work artifacts, as well as teacher curriculum-planning artifacts, were retroactively collected for data analysis. Student artifacts included sticky notes and other written responses to class discussion questions, students' original needs assessment survey drafts, graphic organizers, concept sketches, reflection assignments, slides from students' presentations, materials request spreadsheets, pictures of work sessions, and student work artifacts, as well as some of the artifacts from the wind-mobile and tabletop game mini-design challenges students completed prior to beginning the arthritis-assistive device service-learning engineering challenge. This does not represent an exhaustive list of the various student artifacts that were either produced during the unit or collected after the unit. There were additional artifacts that comprised the corpus of the artifacts data set, though their significance to this unit and the data analysis for this study are minor compared to the significance of those listed above.

Similarly, several artifacts from the unit-planning process were also retained. These artifacts consist of the planning meeting notes and lesson plans Mrs. Daley and I discussed or developed. Additionally, curriculum artifacts also include some of the lesson artifacts, such as instruction documents for various assignments that were distributed or shared with students throughout the unit. While these documents were not produced by students, they were important precursors and scaffolds for student work and represent key anchors within the unit. For example, some of these curriculum artifacts are the design challenge statements or the project charter, which describe the mini and central engineering design challenges that comprised the unit.

Researcher Reflections

As noted at the beginning of this chapter, design experiments or design-based research necessarily positions the researcher as an active participant within the research, a co-designer of the classroom. Furthermore, reflexivity in qualitative research is often regarded as not only an appropriate component of qualitative research, but also perhaps an essential one (Mortari, 2015). Given my intimate role as a co-designer of the project-based service-learning engineering unit, I was also an important stakeholder in the unit. Therefore, my own reflections and insights may be legitimately considered alongside those of the students, the teacher, and the mentors, and as such, are germane to better understanding the design of the unit and initial guiding principles for the design and enactment of pre-college PBSL engineering design units. Indeed, given the dynamic nature of the unit's development, I would be remiss to not consider my own pedagogical decisions, curriculum choices, observations, and experiences in developing and implementing this unit. More specifically, in the last chapter of this dissertation, I offer reflections on the rationales that underscored some of the curriculum decisions and teaching strategies enacted during the unit, as well as features or strategies I consider to be either strengths, weaknesses, or important factors in the design and enactment of pre-college PBSL engineering design units.

Data Analysis

Having described the various data sources informing this study, the next several paragraphs describe the analysis and/or analytical process of each data source. The final paragraph in this section also explain how the analyses of the various data sources heavily informed the third research question, which aimed at synthesizing the perspectives of multiple stakeholders within the unit to offer some initial guidance on designing future PBSL engineering units at the pre-college level.

Survey Data

The analysis for the survey data involved descriptive statistics to discern general patterns within the student perspective. Upon deeper reflection of some of the Likert-type items, it became apparent that the difference between some of the options provided on the original survey was perhaps arbitrary or it was at least difficult to distinguish. For example, while analyzing the data for the survey item "How important is it for you to make the world a better place in some way?" it was difficult to discern or define the meaningful difference between the "quite important" and "extremely important" response options, and similarly between the "slightly important" and "somewhat important" options. Thus, in reporting the results for the most relevant survey items, I combined similar Likert-categories (and their respective frequencies) to create a re-coded three-point Likert-scale. Typically, I combined the Likert responses with a value of four and five together, and similarly, the responses valued at two and three together. However, in reporting the mean of each of these items, I retained the means from the original five-point Likert-scale so as to provide a more precise statistic reflective of the distribution of the students' responses.

Prior to interviewing students, I reviewed the student's individual responses to the survey, highlighting a few key or interesting responses they indicated on the survey. During the interview, I then asked follow-up questions regarding these highlighted responses to better understand the views and sentiments initially expressed in the survey. During the entire data analysis phase, I continued to compare students' individual survey responses to their corresponding interview data to develop a more comprehensive understanding of the emergent themes and patterns of student views regarding the three main constructs of interest in this study.

Interview Data

Analysis of the interview data began with first transcribing all 17 participant interviews. Subsequently, I read through all transcripts, highlighting key quotes or segments that seemed especially relevant to the research questions; often, these highlighted quotes with short marginal notes and memos. I then created two spreadsheets, one for the student interviews and another for the educator interviews, to aggregate the interview data for the respective participant type. Within each spreadsheet, I spliced the data, re-organizing participant responses into excerpts that could be sorted across the broader constructs/themes. For each excerpt, the spreadsheet contained six columns: "primary major theme," "primary sub-theme," "secondary major theme," "secondary sub-theme," "tertiary major theme," and "tertiary sub-theme." The various levels of coding allowed for assigning multiple codes to each excerpt. Similarly, including "sub-theme" coding columns allowed for more specificity in determining patterns across theme. Figure 3.3 shows a sample of the spreadsheet format used for thematic analysis of the interview data. Though Figure

3.3 depicts an excerpt of the spreadsheet used for analyzing student interview data, I used a similar template for the educator interview data.

Figure 3.3

Sample Template of Spreadsheet Format Used for Thematic Analysis of Interview Data

Question	Student	Interview Respondent Excerpt	Primary Theme	Primary Sub-theme	Secondary Theme	Secondary Sub-code	Tertiary Theme	Tertiary Sub-code
What did you think about the pbsl project or the arthritis project in general?	Allie Yapan	0:02:00 Allie: Um, I thought that it was really fun for like learning and uh for like school and everything.	Affect	Fun/engaging Enjoyable Learning Experience	Learning	Enjoyable learning experience		
	Ivy Ivory	Ivy (00:04:12): Um, I thought it was fun. I really enjoyed doing it. And, um, when I did it, um, I was already into engineering. I, um, that's one of the things that I was thinking about doing when I get a job or get older and, um, I thought it was really fun and I enjoyed it.	Affect	Fun/engaging Enjoyable Learning Experience	Authenticity	Unit matches engineering aspirations and interest	Pre-existing engineering interest	
	Alan Indigo	0:03:30: Alan: Umm, I thought it was really cool and very engaging. It engaged everyone and it was very cool actually. It was a lot of fun to do the arthritis project.	Affect	Fun/engaging Enjoyable Learning Experience				
	Oscar Olive	00:02:57.420 Oscar: Um, it was fun. I liked it a lot. Um...	Affect	Fun/engaging Enjoyable Learning Experience				

Analytical Process for Student Interview Data

For the student interview data, I first sorted student interview responses across three separate worksheets with the topics of purpose-in-life, engineering, and project-based service-learning. Within each worksheet, I also sorted student responses by interview questions. These respective sorting heuristics of the student and interview data marked the beginning of the thematic coding phase of the data analysis. I followed a hybrid model of thematic coding characterized by both deductive and inductive coding (Fereday & Muir-Cochrane, 2006). My first-round of deductive coding analysis for the student interviews included six major themes: *social purposefulness; unit preferences; impact of/change after the PBSL unit; engineering notions; engineering interests and aspirations; sense/notions of purpose-in-life*. However, as I reviewed the student interview passages, I also looked for emergent themes and sub-themes, thus inductively coding for additional themes of potential significance and interest.

To assess the trustworthiness of my interpretations of the student interview data and to check for any potential biases in my coding, four independent coders analyzed a subset of the student interview data. After I explained the key themes pertinent to the first research question (i.e., sense/notions of purpose-in-life; social purpose; impact of/change after the unit; engineering notions; engineering interests and aspirations), the independent coders followed an open-coding protocol for the assigned subset of the interview data. The independent coders identified primary, secondary, and tertiary major themes and corresponding sub-themes for each major theme they identified for each excerpt of a student interview. I then briefly discussed the coding produced by the independent coders with them and subsequently reconciled my coding with theirs. I then combined similar codes or nested codes within other codes as sub-themes.

Analytical Process for Educator Interview Data

I followed a similar analytical process for the teacher and mentor interviews. I began by sorting each educator's interview responses according to broader themes: teaching confidence and past teaching/mentoring experiences; engineering teaching/mentoring interests and goals; positive impressions/aspects of the unit; challenges/areas of improvement in the unit; general views on PBSL or engineering; teaching strategies for PBSL engineering design units; reflections on motivating students in engineering (including purpose in life); personal sense of purpose in life; and miscellaneous comments. Initial deductive coding centered around themes such as *areas for improvement, challenges/concerns, positive aspects of the unit, messages about engineering, purpose and/or social purpose, habits of mind/mentality, self-efficacy, student agency, teaching priorities, teaching strategies,* and *teamwork*. Some other inductively emergent themes included *encouraging student ideas, involving expert engineers, equity, exposure, hands-on/physical experience,* and *room for mistakes and failure.*

To verify the trustworthiness and accuracy of my coding for the educator interview data, two independent coders analyzed subsets of the educator interview data set. This time, I provided the two independent coders a codebook of initial major themes I had identified during my first round of coding. I instructed the independent coders to use the identified codes and codebook to code primary, secondary, and tertiary major themes for each interview excerpt. However, the independent coders used open-coding to specify any sub-themes to the major themes they identified as being relevant to an excerpt. I reconciled my coding with that of the two independent coders. Like the student interview data, I then combined codes or nested codes that related to each other.

It should be stated that though I considered both the teacher's and the mentors' perspectives together in answering the second research question, I was cognizant of the nuances between these perspectives. That is, Mrs. Daley's perspectives are, of course, reflective of her experience as a classroom teacher who had little previous engineering or engineering-teaching experience and who was intimately involved in the design and enactment of the unit from its very start. On the other hand, the three mentor perspectives are representative of expert engineers who were mostly involved during one or two particular phases ("Create" and "Test and Improve") within the longer, multi-step unit and design process. Both perspectives are nevertheless valuable. Analyzing them in tandem, however, examines the intersection and synthesis of perspectives of the two domains of expertise represented by the educators: education and engineering.

Final Coding for Both Interview Sets

The final collection of major themes and sub-themes for each data set (student interview data and educator interview data), resulting from these multiple rounds of coding then, represent the salient findings that address the first and second research questions and are further discussed in the two subsequent chapters. The corresponding codebooks for the final, salient themes for the student and educator interview data are also found in Table 4.1 in Chapter Four and Table 5.1 in Chapter Five, respectively.

Artifact Data

The analysis of the student artifact data served to supplement the interview data. Their inclusion in the data corpus for this research allowed me to identify concrete markers (i.e., activities or events) throughout the unit that contributed to or were exemplary of certain views or ideas about engineering, (social) purposefulness, or student learning through the PBSL engineering unit. Thus, when discussing the results of these analyses, I will present these alongside my discussion of the findings from the student interview data analysis.

To analyze these artifacts, I took a content analysis approach, also characterized by thematic coding. The thematic coding for the artifact data followed an inductive approach in that codes were derived from notable excerpts and/or images from the selected artifacts, though I also prioritized any emergent themes that especially paralleled or alluded to corresponding interview data. As such, the coding for these artifacts particularly focused on student reflections on their learning, conceptions of engineering, (social) purposefulness, and how these notions may have related to each other as well as how it unfolded throughout the unit. Thematic coding for the artifacts occurred primarily as marginal notes on printed or digital, de-identified copies of the artifacts.

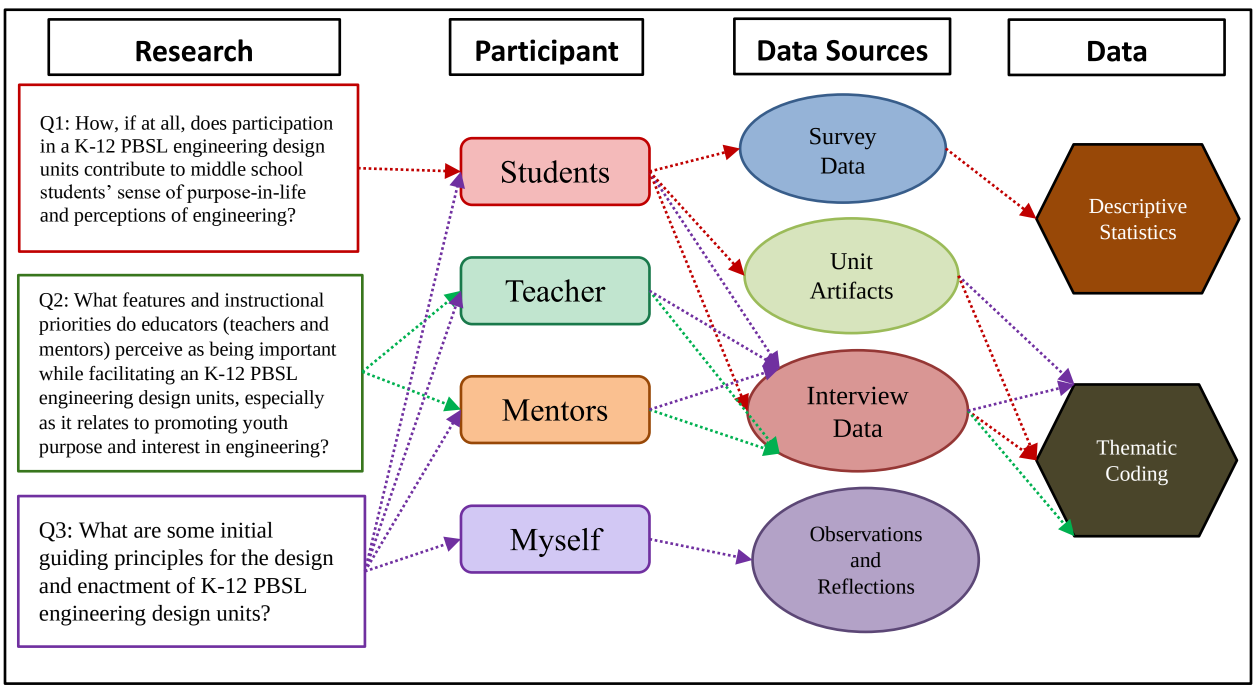
Analysis for Third Research Question

The analysis for third research question, “What are some initial guiding themes for the design and enactment of K–12 PBSL engineering design units?” relied on synthesizing the patterns across themes from the student survey data, the interview data (from all three stakeholders), and the unit artifacts. I then triangulated and interpreted these patterns within the lens of my own reflections and notes from my experience as the participant-researcher during the development and implementation of the unit. Since the third research question is better answered when considering the entirety of the findings reported in this thesis, I answer this third research question in the sixth and final chapter, the Discussion chapter.

To help the reader better understand the analytical approaches undertaken here, Figure 3.3 presents a schematic representing the relationship between the research questions, the data sources, and the analyses discussed above. In essence, this schematic (Figure 3.3) depicts the research design of this study.

Figure 3.4

Schematic of Overall Research Design



CHAPTER FOUR:
FINDINGS PART I: STUDENT PERSPECTIVES

This chapter documents the findings pertinent to the first research question: "How, if at all, does participation in an engineering design PBSL unit contribute to middle school students' sense of purpose in life and perceptions of engineering?" The chapter thus explains the significant themes that describe the students' perspectives regarding three overarching aspects of this research: the PBSL unit, their sense of purpose in life, and their perceptions of and interests in engineering. The findings presented here primarily draw from the interview data of the 13 students who participated in the interviews. It also incorporates post-unit survey results from the same students (with the exception of one student who did not complete the survey) and some excerpts of student-generated artifacts from the unit, as well as a few of my personal observations, albeit to a lesser extent. Wherever possible, the discussion of each finding includes a tally of the number of students whose interview responses corresponded with the themes noted below. Furthermore, the discussions of these themes present typical or notable quotes or excerpts to illustrate how these themes were evident in the student interviews or artifacts. Several of the themes discussed here were salient in that they were recurring across at least a third of the student interviewees. However, this chapter also presents a few themes that were pertinent to a fewer number of students because they illustrate other noteworthy perspectives that are relevant to the research question.

This chapter is structured into three major sections corresponding to the student perspectives on each of the three overarching dimensions of this research: the project-based service-learning engineering design unit, purpose in life, and engineering. Six primary themes generally encompassed student perspectives on the project-based service-learning (PBSL) engineering design unit: *impact of/change after the unit*, *affect, meaningfulness*, *learning*, *teamwork/collaboration*, and *agency*. The second major section of this chapter describes the findings regarding student perspectives on the purpose in life dimension. These perspectives could be summarized within three primary themes: *notions of purpose in life*; *student purposefulness;* and, *career aspirations.* The third major section in this chapter describes students' perspectives on engineering. Two primary themes emerged with regard to the engineering dimension: *engineering notions* and *engineering interests*. Almost all of these primary themes in each of the overarching dimensions (except for *agency* within the PBSL dimension) had several sub-themes, which are all further defined and elaborated upon in the ensuing pages. Table 4.1 also presents a codebook of the primary themes for each of the three major dimensions as well their definitions.

While certain themes may be presented within the context of one of these core dimensions, it is important to note that there was much overlap between these themes across all three dimensions. For example, while *agency* was a primary theme within the discussion on student perspectives on the PBSL unit, it underscored many of the other themes in all three dimensions. Similarly, *social purpose* and *career aspirations* were recurrent sub-themes under several primary themes across all three core aspects, as well. However, the discussions of these themes are parsed across these core aspects in order to better draw out their nuances in relation to these three aspects. For example, by discussing *social purpose* within the context of students' perspectives on the PBSL unit, purpose in life, and engineering separately, we can see how social purpose was also evident in student reflections on the unit, their notions of purpose in life, and in their views of engineering. With this in mind, this chapter first expounds upon the predominant findings regarding the students' perspectives on the PBSL engineering design unit.

Table 4.1

Codebook of Primary Themes for Student Interview Data

Overarching Aspect/Dimension of Student Perspectives	Primary Themes	Definition
Project-Based Service Learning (PBSL) Engineering Design Unit	Impact of/Change after the Unit	Various aspects, including understandings, attitudes, feelings, aspirations, etc., which students indicated may have changed or shifted as a result of or after participation in the PBSL unit. Could be either a positive, negative, or neutral change (i.e. no change/shift)
	Affect	Students' affective responses or feelings toward the PBSL unit, PIL, or, engineering, or other general affective comments
	Meaningfulness	Reasons why students said the project or aspects of the project were meaningful to them.
	Learning	What students' perceived they learned about. Could include topics, skills or concepts
	Team work/Collaboration	Students' comments regarding working in a group/a team/together. Can include reflections about positive or negative aspects regarding the collaborative process or experience.
	Agency	Students' sense of being able and capable of doing something or taking responsibility and ownership of something. Typically signaled by students use of language like "I can," "I could," 'I did" or "I would be able to."

Table 4.1, *cont.*

Overarching Aspect/Dimension of Student Perspectives	**Primary Themes**	**Definition**
Purpose in life	Notions of Purpose in life	Student reflections about the concept of "purpose in life." Includes their explicit or implicit personal definitions or apparent associations in their discussions of purpose in life
	Student Purposefulness	Students' descriptions of their own purpose in life. Could also include students' reflections on their values and what's important to them. Classification of student purposes mostly based on Bronk's (2014) typology of purposes.
	Career Aspirations	Student descriptions of their career aspirations, if any, as well as their desires, goals, and priorities regarding their future careers.
Engineering	Engineering Notions	Student perspectives of what engineering is, its nature, and its implications for the broader world. Includes their perspectives on "doing" engineering, what it is, or their notions of it as a profession/career.
	Engineering Interests	Indications of students' interests in engineering both at the time of data-collection and in the future. Also includes reasons why students might be interested in engineering.

Student Perspectives on the PBSL Engineering Design Unit

Student perspectives of the PBSL unit seemed to coalesce around six primary themes: *impact of or change after the unit*, which encompasses various aspects of student thinking including their understandings, attitudes, feelings, interests, and aspirations, which may or may not have changed or shifted, either positively or negatively, as a result of or after the unit; *affect*, or students' affective responses or feelings toward the PBSL unit; *meaningfulness*, which describes some of the reasons students cited as to why the unit or aspects of the unit were meaningful or significant to them; *learning*, which encompasses students' perceptions of what they learned from the unit; *teamwork/collaboration,* which explains student reflections around working in a team and their team dynamics; and *agency,* which refers to students' expressions of their sense of ability or capability in helping their community or in doing engineering, or their sense of ownership and responsibility in these regards.

Impact of/Change After the Unit

The *impact of/change after the unit* theme refers to students' self-described experiences of whether or not the unit impacted various aspects of their thinking about engineering, their purpose in life, or their career aspirations. It should be stated at the outset that the analysis of this theme does *not* refer to nor claims any paired sample pre-post analyses or comparisons. Rather, this theme represents what students perceived to be the changes (or lack thereof) as a result of their participation in the PBSL unit. As noted above, student comments about the impact of the unit particularly pertained to their interests and understanding of engineering and their sense of purpose in life. Students either described an increase in these aspects or no shift or change in these aspects (i.e., the unit was neutral in influencing these aspects); none of the students reported decreased or negative changes in these respects after the unit.

To provide a broader overview of how each student interviewee perceived the impact of the unit, Table 4.2 presents the aggregate profiles of each student interviewee's interest in engineering, their sense of purpose in life, and their future career aspirations. It also indicates whether the student indicated a change after the unit in one or more of these areas. In addition, the following paragraphs briefly outline the students' self-described impacts of the unit on their interests in and understanding of engineering as well as their sense of purpose -in-life. However, elements of these themes are also further discussed throughout this chapter.

Table 4.2.

Student Interviewee Profiles Based on Post-Unit Interviews

BIOGRAPHICAL/ DEMOGRAPHIC INFORMATION			SERVICE INVOLVEMENT		SENSE OF PURPOSE IN LIFE		ENGINEERING INTERESTS AND EXPERIENCES					MISC. INFOR-MATION
Student Pseudonym	**Gender**	**Race/Ethnicity**	**Service involvement** (Yes, No)	**Service involvement description** (if applicable or available)	**Existing sense of PIL (before unit)?** (Yes, Slight, No, Unsure or unclear)	**Perceived impact of unit on PIL?** (Yes, Slight, No, Unsure, No shift)	**Engineering interest before unit?** (Yes, Some, No, Unsure or unclear)	**Perceived impact of engineering interest after unit?** (Yes, Slight, No, Unsure, No shift)	**Past Engineering participation/experiences?**	**First awareness of engineering?**	**Family/community members who are engineers?**	**Misc. Notes**
Alan Indigo	Male	Hispanic/ Latino	Yes	Boy scouts	Slight	Yes	Yes (High)- aerospace engineer	Slight increase	Not very much prior to unit; Made an LED birthday card in fourth grade; Summer coding camps	5 or 6 years old	Father; Older brother studying to be an engineer	Joined the school and project toward the end of the unit (during the "Create and Testing" phase); Alan's still considering various possible careers, but some future career aspirations include being: an astronaut, a computer engineer or and electrical engineer.
Allie Yapan	Female	Mixed Race	Yes	Altar serving and choir	Yes	Yes	No	Slight increase	In school- discussion in a career unit	4th-grade	No	Allie's father was one of the inspirations and service-partners for the unit/design challenge. Future career aspiration is to be an orthodontist.

Table 4.2, *cont.*

BIOGRAPHICAL/ DEMOGRAPHIC INFORMATION			SERVICE INVOLVEMENT		SENSE OF PURPOSE IN LIFE		ENGINEERING INTERESTS AND EXPERIENCES					MISC. INFOR-MATION
Anastasia Azure	Female	Hispanic/ Latina	No Info Avail-able		No/ Unsure	Unclear	No	Slight increase	Several past school experiences with engineering; Science fair	Early childhoo d	Possibly an uncle/not sure	Still unsure about future career aspirations, but would like to work closely with animals
Elijah Amaranth	Male	Caucasian	Yes	Altar serving	Yes	Slight	Yes	Yes	Legos/Lego Robotics	"When I first got Legos"	No/Not sure	Interested in/likes learning about space/astronomy and math; Future potential career aspirations include being: a priest; or, an engineer.
Ethan Orange	Male	Mixed Race	Yes	Clothes drive	Yes, slight	No/No shift	No	No shift or change (Does not have a personal interest in engineering)	4th-grade engineering project on model bridge making	4th grade-from grandfat her	Grand-father	Future career aspiration is to be an entrepreneur or an investor.
Ezra Amethyst	Male	Caucasian	Yes	Altar serving	Yes/ Unsure	No	Slight	No shift or change	Unsure/possible participation in formal STEM camps; Hobby in model toy cars	Early childhoo d	No	Still unsure about future career aspirations
Ingrid Navajo	Female	Hispanic/ Latina	No	In school: Religion in Action service projects	Yes	Yes	Yes	Yes-increased	Girls Math/Engineering One-day Camp (multiple years)	Early childhoo d	Cousin	Future career aspirations is to be either a doctor or a veterinarian.

Table 4.2, *cont.*

BIOGRAPHICAL/ DEMOGRAPHIC INFORMATION			**SERVICE INVOLVEMENT**		**SENSE OF PURPOSE IN LIFE**		**ENGINEERING INTERESTS AND EXPERIENCES**					**MISC. INFOR-MATION**
Ivy Ivory	Female	Caucasian	Yes	Girl Scouts; Self/Family-visiting senior assisted living centers, shelters, Hurricane relief; Choir at church	Yes	Yes	Yes (High)	No shift/ Slight increase	In school: first grade design project; Out-of-school: IBM camp; making projects	1st grade	Uncle; family friends	Future career aspirations include being: an Olympic swimmer; an engineer, or a marine biologist.
Ophelia Emerald	Female	Caucasian	Yes	Altar serving; "Shred Day"	Slight	Yes	Yes	No shift or change	STEM camp; Past school engineering projects: model bridge or pencils, designing a model astronaut landing device; At-home/personal engineering projects	Early childhoo d	Father; Uncle	Still unsure about future career aspirations, but some possibilities include: working with animals, being an engineer, or, being a chemist.
Oscar Olive	Male	Hispanic/ Latino	Yes	Serves at church as an usher	Yes	Slight	Yes (High)- structural or mechanical	No response available	Hobby in model toy cars; Reads about engineering feats	Early childhoo d	Cousin	Oscar's grandmother was also one of the inspirations for the design challenge. Future career aspirations is to be a structural or mechanical engineer.
William Mauve	Male		Yes	Altar serving; Serves with *Mobile Loaves and Fishes*; Boy Scouts	Slight	Yes	No	Yes-increased	At-home/personal engineering projects	Earlier childhoo d	No	Still unsure about future career aspirations, but considering priesthood or a career in sales as possibilities.

Table 4.2, *cont.*

BIOGRAPHICAL/ DEMOGRAPHIC INFORMATION			**SERVICE INVOLVEMENT**		**SENSE OF PURPOSE IN LIFE**		**ENGINEERING INTERESTS AND EXPERIENCES**					**MISC. INFOR-MATION**
Yohan Auburn	Male	Caucasian	Yes	Altar serving; Building mountain bike trails	Yes/ Unsure	Yes	Some (slight)	No shift or change	Hobby building/making-obstacle courses	4th-grade	Most of his uncles	Future career aspiration is to be a race car driver

Interests in and Understanding of Engineering

With regard to student interest in engineering, at least seven of the 13 (54%) student interviewees indicated that the PBSL unit at least slightly increased their interest in engineering. For example, Anastasia commented,

> It's a little more interesting, yeah. . . . Well, when I think of engineers, I usually thought "Oh, like, mechanics," and I see that it's a lot bigger than that—more things that have to do with things that I like. Like, it could be like designing and that's kind of interesting, I guess.

Here, Anastasia described how the unit helped her see that engineering entails more than just mechanics and could include aspects that align with her existing interests in design. Similarly, Allie, Alan, Elijah, Ingrid, Ivan, and William indicated that the unit increased their interest in engineering at least a little. These students typically expressed that this was either due to their enjoyment of doing engineering within the PBSL unit or their increased understanding of what engineering is. The discussions on *affect* and *learning* elaborate on both these reasons.

On the other hand, five students reported no shift or change or a neutral influence of the unit on their interest in engineering, with it staying about the same before and after. For some students, such as Ivy, Alan, and Oscar, this was because they already had a high preexisting interest or aspiration in engineering, and the PBSL unit cemented their interest rather than increased it. Others, such as Ethan, already had a different career interest and aspiration such that the unit did not necessarily improve his interests in engineering from a career perspective. Ezra, Ophelia, and Yohan had some preexisting interest in engineering, but they described the unit as "not really" shifting their interest in engineering. There was no direct response available from Oscar regarding the question of whether his interest in engineering shifted as a result of the unit. However, Oscar had a high preexisting interest in engineering and indicated he would like to continue studying engineering and pursue a career in it. None of the student interviewees said that their interest in engineering decreased as a result of the unit.

Although, in their interviews, students were almost evenly split as to whether the PBSL unit impacted their interest in engineering, interestingly, the survey results (the data for which was obtained prior to the interviews) show an overall greater inclination to either continue studying engineering or pursue engineering as a future career. Figure 4.1 and Figure 4.2 summarize students' survey responses when asked how likely they were to continue studying engineering or pursue an engineering career after participating in the PBSL engineering project.

Figure 4.1

Frequencies of Student Survey Responses to Likelihood of Studying Engineering after Participating in a PBSL Engineering Project

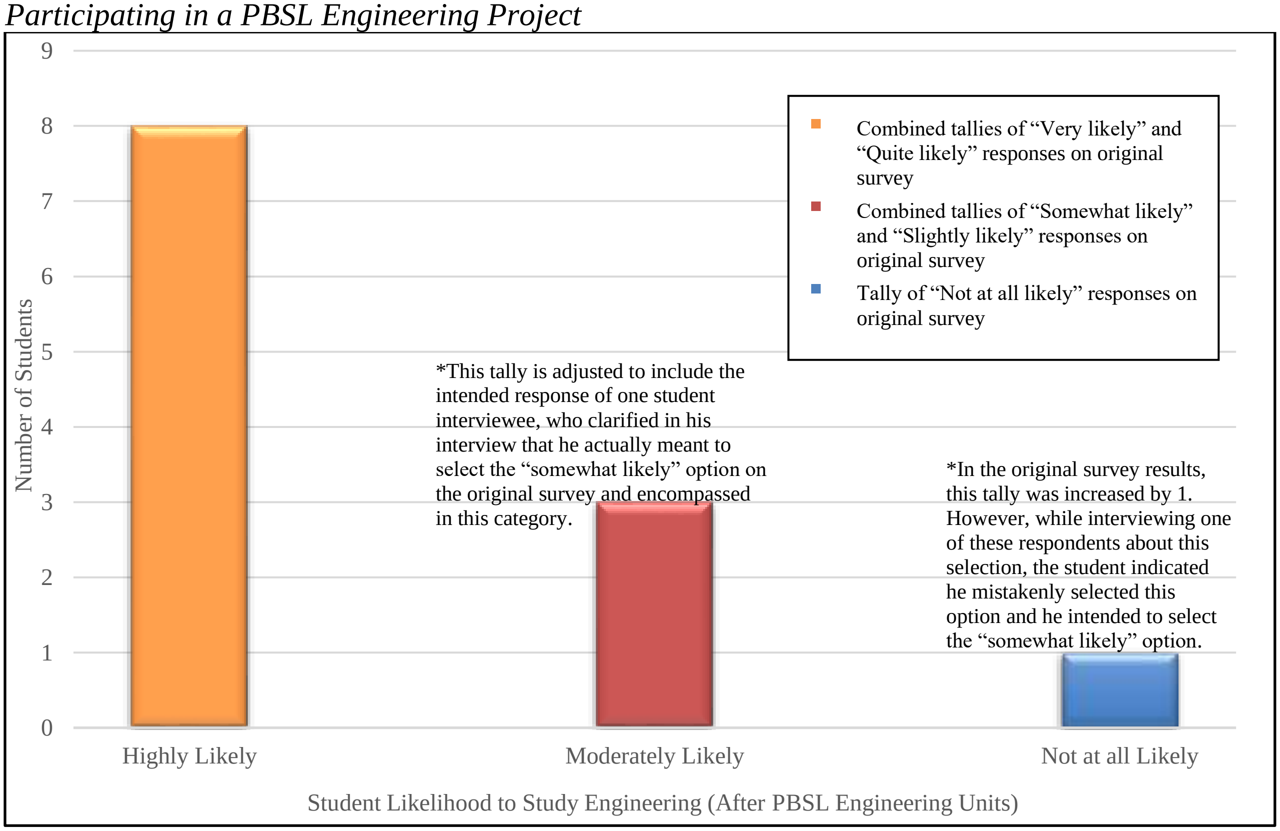
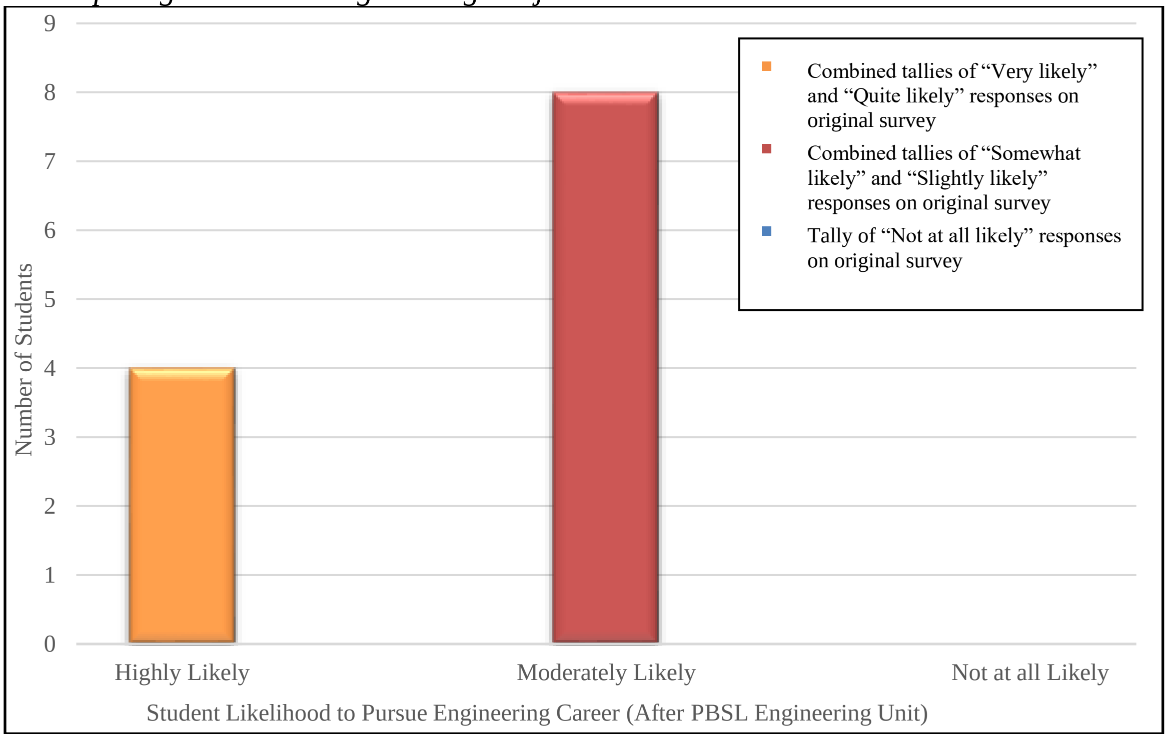


Figure 4.2

Frequencies of Student Survey Responses to Likelihood of Pursuing an Engineering Career after Participating in a PBSL Engineering Project



As shown in Figure 4.1, at least eight of the 12 students who completed the survey indicated that, after participating in the PBSL engineering unit, they were highly likely to study engineering in the future, while another three were moderately likely to do so. The mean for this five-point Likert-type item (with a scale of 1, "Not at all likely," to 5, "Very likely") was 3.67.

Similarly, as Figure 4.2 shows, four students indicated that they were highly likely to pursue an engineering career in the future because of the PBSL engineering unit, while another eight students responded that they were moderately likely to do so. The mean for this five-point Likert-type item (with a scale of 1, "Not at all Likely," to 5, "Very likely") was 3.33. While there can be multiple reasons or factors as to why students might be inclined to study engineering or pursue an engineering career, some of which may or may not stem from interest in engineering, these figures and aforementioned student comments nevertheless show that the PBSL unit had at least an influence in promoting students' inclination to pursue engineering in the future.

About 11 of the 13 (85%) student interviewees also commented that the PBSL unit impacted their understanding of engineering, while two students indicated that it did not really impact their understanding of engineering. More details about what understandings about engineering students gained from their participation in the PBSL unit are provided in forthcoming discussions of the *learning* and *engineering notions* themes later in this chapter. Briefly however, students seemed to indicate that their understanding of engineering improved regarding their knowledge of the nature and process of engineering.

Sense of Purpose in Life

When asked whether their participation in the PBSL unit impacted their sense of purpose in life, 10 of the 13 (77%) students responded that it did, either slightly or to a greater extent. Anastasia's response was somewhat ambiguous and referred more to how "it showed [her] that some people can't do certain things," likely referencing the mobility struggles of the service-partners, but she did not explicitly comment that the unit impacted her sense of purpose in life one way or another. Two other students, Ezra and Ethan, said that the unit did not impact or shift their sense of purpose in life. Ezra was not quite sure how to explain why he did not feel the unit impacted his sense of purpose in life, while Ethan who, as noted above, had a preexisting and clearly-defined career goal, felt that the unit did not have an impact on his sense of purpose in life because it did not change his career aspirations. He explained, "I don't think it did, because I never really thought of becoming an engineer and I don't feel like I want to. . . . Because when—I would say at least a year ago—I felt like I wanted to be an entrepreneur and an investor, because that's what I want to do." Among the 10 students who did indicate that the unit impacted their sense of purpose in life, this impact largely seemed to relate to a sense of social purposefulness or their career aspirations.

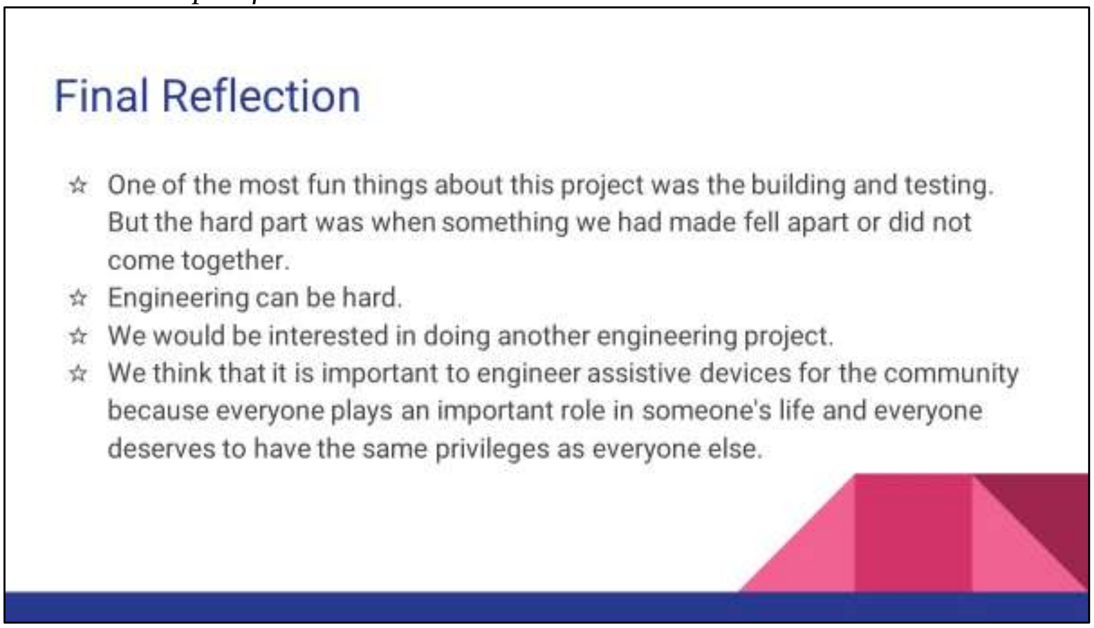
Social Purposefulness. One emergent theme of how the unit positively impacted students' sense of purpose in life was that it helped foster a sense of social purposefulness. This was often described by students in terms of "helping" others or the community. For example, Alan commented, "It made me want to help more people, like do something more about helping people." Similarly, when asked about the unit's impact on his sense of purpose in life, William responded, "Yes it did. I think it did because I—it was very fun and like, if I do more of that, maybe, maybe like my sense [of purpose] in life will be a lot more clearer by just helping people and like having teamwork with others." While both Alan and William's responses were typical of students' reflections on how the PBSL unit impacted their sense of purpose in life, William's comments were especially noteworthy because his sense of social purposefulness was both tied to helping people and working in a team toward a common goal.

For some other students, this post-unit sense of social purposefulness was also tied to their views on engineering. For example, in response to this question, Ophelia reflected, "I think it did because it showed me that there's more to engineering than just inventing stuff. I mean, like it is inventing, but not just random things, but like to help people." While Ophelia's career aspirations were still somewhat undecided, engineering was among the possibilities she was considering. It was thus significant that she affirmed that her sense of purpose in life was impacted by the PBSL project's emphasis on the potentially socially purposeful aspects of engineering.

This notion of engineering as a vehicle for helping the community was also present in the student artifacts. For example, one team's final design presentation contained a reflection which stated, "We think that it is important to engineer assistive devices for the community because everyone plays an important role in someone's life and everyone deserves to have the same privileges as everyone else." Figure 4.3 depicts the relevant slide from this team's presentation.

Figure 4.3

Excerpt of Students' Final Design Presentation Articulating a Connection Between Engineering and Social Purposefulness



Career Aspirations. Another perceived impact of the unit seemed to be in helping some students clarify their career aspirations. For some students, such as Oscar, Ivy, and Elijah, the PBSL unit helped increase their desire or aspirations in engineering. In his response to the interview question as to whether the PBSL unit impacted his sense of purpose in life, Oscar said that the unit had a slight impact and explained, "It helped me understand engineering more, so that helps."

For Ingrid, while the PBSL unit did not necessarily increase her ambitions in engineering, it was still impactful in helping her clarify her career interests and aspirations. In the following dialogue sequence, Ingrid explains this:

> *Sneha:* Did your participation in the PBSL project, or the arthritis project, impact your sense of meaning or purpose in life? Why or why not?

> *Ingrid*: It did because when I was engineering that device, it really helped me think of how I could help people in the world. Like I will admit, my future career how it really impacts my thinking of it. I'm like, "This small device can impact a lot of people like to help them." And thinking of that is actually what started me thinking about being a doctor or a pediatrician or something, another care like that, or vet to help animals.
>
> *Sneha*: Can you say more about that? So how did that—were you not thinking about being a doctor before the project or was it—?
>
> *Ingrid*: Not really, I would like think of it, but then like, "Oh, I don't want to be it anymore." . . . 'Cause you know, like when you're younger, you don't really know what you want to do when you grow up, or like you're thinking, but then you don't want to do it. Like I wasn't like thinking of being a doctor until I started that device and saw how small things can help impact a big community of people.

Ingrid's comments here are multi-faceted. For one, Ingrid's increased interest in medical care (for humans and/or animals) is rooted in a sense of social purposefulness and a desire to help others. Furthermore, as her comments in the last lines of this dialogue indicate, the experience of designing an assistive device for a medical condition seemed to have impressed upon her the potential for effecting social/community impact within the medical field. As a result, this helped her become more certain about her desire to be a medical professional when she would otherwise previously wax and wane in her career aspirations.

Like Ingrid, the PBSL unit helped Ethan also clarify his career aspirations, albeit in a very different way. Although Ethan indicated that he did not think the unit impacted his sense of purpose in life, he nevertheless seemed to gain clarity as to what engineering is to help him affirm that this was not a future career route he necessarily wanted to pursue, preferring his preexisting aspirations to entrepreneurship and investment. It is also worth noting that for both students, their career aspirations seemed inherently tied to their sense of purpose in life; this was a recurrent theme across the student interview data corpus and will be discussed further later in the presentation of findings related to *student purposefulness*.

Affect

The *affect* theme broadly encapsulates students' feelings toward the PBSL unit and their experiences with it, both generally and specifically. Two prevalent sub-themes of affect emerged under this theme. In the first theme, students described the PBSL unit in terms of *an enjoyable experience*, often describing the unit as being "fun." The second theme describes students' *sense of pride and personally feeling good* as a result of designing something to help others. Both sub-themes are elaborated upon below.

An Enjoyable Experience

All 13 (100%) participating student interviewees referenced the unit as being an enjoyable experience that was either "fun," "engaging," "great," "good," or "interesting" at some point during their interviews. When asked generally what they thought about the project, students used one or more of these adjectives or other affirmative synonyms to describe their feelings toward the unit. Students either used these adjectives to describe the unit as a positive learning experience or just as an enjoyable experience at large. For example, Ingrid commented, "I really enjoyed it a lot. It was really fun. And, it was a fun learning experience." Similarly, Alan expressed similar sentiments when he said, "I thought it was really cool and very engaging. It engaged everyone, and it was very cool, actually. It was a lot of fun to do the arthritis project." Here, Ingrid's comment was exemplary of the types of comments which expressed positive affective dispositions toward the PBSL unit as a learning experience. On the other hand, while Alan's comment did not necessarily qualify his sense of fun within the context of learning, he used these adjectives to describe the general nature of his experience participating in the unit.

Some students' references to the unit being "fun," "great," or "good," also emerged in the context of discussing specific aspects of or experiences within the unit. Some students saw the unit as being fun particularly because it aligned with their preexisting interests in engineering, which they generally viewed as fun. For example, Ivy expressed, “I thought it was fun. I really enjoyed doing it. And, when I did it, I was already into engineering. That's one of the things that I was thinking about doing when I get a job or get older, and I thought it was really fun and I enjoyed it.”

Other students also expressed positive feelings even when they experienced frustration during the unit. In following dialogue sequence, William described having mixed emotions when asked how he felt when something seemed to go wrong during his team’s design process:

> *Sneha*: When something went wrong [slightly inaudible], did you . . . how did that make you feel? Or, were you excited to do it again, were you frustrated?
>
> *William*: It was kind of like a mix of emotions. Like, it was kind of overwhelming and fun at the same time.
>
> *Sneha*: Okay. Can you tell me more?
>
> *William*: Um, like I thought it was kind of like from different times, it was like frustrating, exciting. Yeah, it was just like a bunch of mixed emotions.

Though he experienced moments of frustration, William’s comments, here and elsewhere, showed that he overall felt positively about the unit, seeing it as a fun and meaningful experience, much like several of his peers.

Feeling Good About and Pride in Oneself

Another recurring theme of student affect was a sense of feeling good about oneself, a sense of pride, or a sense of personal importance stemming from the service aspect of the unit. More specifically, when asked how they felt designing something for someone who needed their help, at least nine (69%) students expressed that the experience of helping someone made them feel good about themselves. For example, Allie commented, “I felt really like good inside because I knew I was helping someone. . . . Because sometimes you don't really get the time to help someone in that way and so being able to do that really made it feel nice." Here, Allie's positive feelings directly derived from helping someone. Furthermore, Allie seemed to indicate that while helping others was important to her, she did not necessarily get many opportunities to do so, which made the experience of doing so within the context of this unit particularly special for her. Ethan echoed a similar sentiment when he responded to this question with, "I felt good, because I know that I can potentially help that person with [an] issue that they have." Like Allie and Ethan, most of the other student interviewees also noted that the knowledge of helping someone inspired a sense of personal satisfaction.

For some students, this sense of personal satisfaction was also articulated as a sense of pride or importance in being able to help someone. For example, Alan explained that he felt proud to help ease the struggles of someone suffering from a medical condition, "It felt really good, and I felt proud and happy that I helped someone in need of that. I helped someone who is struggling with arthritis and in pain to make it easier for them." Similarly, for a few others, such as Ingrid, the experience of helping someone achieve something they could not before also helped her feel important herself; she commented,

> Helping someone do something that they can't do really makes me feel like important and like happy, because I know like that helping someone that has an issue that they can't do, something that maybe they enjoy to do, but they can't do it since they have [inaudible] problems or they [have] muscle problems or hearing problems, or something like that.

Here, Ingrid seemed to derive pleasure in helping others reclaim their ability to do and enjoy things that were otherwise hampered by physical ailments.

Meaningfulness

The unit was *meaningful* to students in at least three different ways. First, the unit was meaningful for students to the extent that it was *personally important* to students that they try to help others. Second, for some students, the impetus for the design challenge was also *personally* *relevant or significant* in that these students had relatives who suffered from arthritis. Finally, several students perceived the unit to be authentic in nature and this *authenticity* made the unit more meaningful and memorable.

Personal Importance

One recurring theme of meaningfulness was that helping someone was personally important to students. Indeed, all 13 (100%) of students indicated that it was important to them to help others. When asked whether designing something for someone who needed their help was important to them, students, such as Allie, Ivy, Oscar, Ethan, Ophelia, Ivan, and Alan, explained that they personally valued helping others. For example, Ivan emphatically responded, "Yes, because they're, they're people. You have to be, you have to be kind to them. You can't just let someone get—you can't just let someone hurt, because you have to help them!" Here, Ivan expressed a desire to help others, which stemmed from a sense of empathy for other people in general. Similarly, Alan's response to this question also indicated a deeper moral conviction as to why helping others is personally important to him, as is evident in this dialogue sequence:

> *Alan*: Um yeah, I think it's important cause we help out people and it's the mission of [the school] to do that—to help other people. And it feels good, like you're following the good way.
>
> *Sneha*: "The good way?" Is that what you said?
>
> *Alan*: Yeah, "the good way."
>
> *Sneha*: And what's "the good way?"
>
> *Alan*: Like following the ways of God, like what He would do.

Here, Alan both noted the alignment of serving others to the school's mission and, even more broadly, to his personal faith and religious convictions.

Personal Relevance

Another reason why the service-oriented design component of the unit was meaningful was that for at least three students (23%), it was personally relevant. For Allie, Ivy, and Oscar, in particular, designing something for someone who needed their help held special significance because they had family members who struggled with arthritis. Indeed, the design challenge originated from the needs-assessment survey conducted by Allie and Oscar's group, which focused on identifying needs within their respective family circles. Allie noted that designing something that her father could potentially use as an arthritis patient "made it more meaningful and important and more, like, motivational." Similarly, Ivy noted,

> Yeah, it was really important to me because my grandma does have arthritis and my grandpa, she has to take care of my grandfather because he had something going on and like if I could make something to help her make her life easier to help him, it would—it would mean a lot.

Oscar also expressed similar sentiments, noting that it was important for him to design something that could potentially help his ailing grandparents.

Authenticity

One especially key theme of meaningfulness emergent in the student interviews was the perception of the unit's authenticity. At least eight (62%) students perceived their participation in the PBSL unit as being authentic in their contribution to their community or society, in their experience of "doing" engineering, and as a general learning experience. With regard to the former, students articulated a sense of actually helping members of their community through their assistive device designs. Perhaps this sentiment was best captured in the following dialogue sequence from Anastasia's interview:

> *Anastasia*: Uh, it was pretty cool 'cause now, you're actually helping someone. And before, like with the projects that we've done in school, they're just, like prototypes—those are prototypes. So, you use them once and you usually throw them away, so.

Sneha: So, what was different about this one than the other ones?

Anastasia: Um, well the other ones are not exactly like this; they were usually for science fair projects. So, like you're building, like, a boat or something that would help the egg not crack. It's not like you're building something to be used to help you do things.

Sneha: And did you get a chance, in this project, to see your device helping someone or something?

Anastasia: Yeah. A lot of people used it. And, like when they used it, they were like, "Wow, it's a lot easier because now I can do this and this." It actually helped them open the jar in our case.

Here, Anastasia reflects on how the nature of the design challenge in the PBSL unit differed from those of previous design challenges. Anastasia's use of the words "actually helping" multiple times within this dialogue sequence indicates that she viewed her team's design as being an authentic and real contribution to the members of her community for whom this device was intended and designed. She compared the purpose of this design challenge to other design challenges from her past, suggesting that the nature of the PBSL unit differed in that it was oriented toward engineering something that could actually be used, as opposed to one-off prototypes.

Ivy and Alan also echoed Anastasia's sentiments when asked what they liked about the project. Ivy commented,

And, I liked how we did it on something that was like a thing in this world and it was actually happening. And so, we are helping people with arthritis, like we're doing something in the world. That's what I enjoyed about it."

Similarly, Alan noted, "I liked that like we learned how to build stuff—build stuff and real things that could help out real people because it feels good to do that and it's fun to build real stuff." Here again, Ivy and Alan's use of words like "actually" and "real" indicates a sense of an authentic contribution to society or helping others through their teams' design of an assistive device.

Students also perceived the PBSL unit to be an authentic experience of engineering (to the extent of what they understood to be engineering). When asked whether and how the PBSL unit changed or impacted her understanding of engineering or what engineers do, Allie responded,

> Um well I think, it changed or like my perspective of what they do because I was able to really understand what they have to do because I got to do like a smaller portion of what they do or like a smaller thing.

The latter portion of Allie's response here suggests that Allie viewed the PBSL unit as a scaled-down yet authentic version of a real engineering endeavor.

This sense of an authentic engineering experience also seemed to especially resonate with students who already had interests and aspirations in engineering. Though she may not have had strong preexisting interests and aspirations in engineering, Anastasia also seemed to perceive this unit as an authentic representation of engineering. In the preceding dialogue sequence, Anastasia's comments also seemed to indicate that she saw the endeavor of engineering a device that could actually be used as an authentic engineering design challenge. Other students who had strong interests in engineering, such as Ivy, Alan, and Oscar, saw the PBSL unit as aligning with these interests and as an opportunity to engage in "real" engineering. When asked what he liked about the project, Oscar noted,

> That we got to construct something and go through that whole process of engineering. And we explained what like, what an engineer does and stuff like that. So that was fun because I want to become an engineer. But I'm not going to become a medical—or the biomedical engineer. . . . I want to become like the structural or mechanical.

Overall, Oscar saw his learning through the PBSL unit as both experiential and didactic, especially with regard to engineering. For these reasons, it was meaningful to him because it resonated with his preexisting interests in engineering. Although the unit illustrated a different discipline of engineering than the one Oscar was interested in, Oscar nevertheless went on to explain how the unit helped him better understand other disciplines of engineering, including biomedical engineering, of which he had a cursory awareness.

Students also seemed to view the PBSL unit as an overall authentic learning experience. More specifically, students saw the unit as being authentic in its incorporation of various community members, demonstration of mentorship and habits of mind, and real-world application. For William, it was especially meaningful for him to present his team's designs to real audiences that included the service partners and other adult members of the school community: "Well yeah, I liked, um...like presentating [sic] in front of all the other people so they could like know like what we did and how it could help people with arthritis." For Anastasia, it was further meaningful for her to have authentic mentorship from the teachers and engineering mentors, especially to help her team persist through moments of failure; she noted,

> It was meaningful 'cause, uh, you could do things that people usually can't do . . . like as a class, with teachers helping you show how to design something, and like what are the steps, and how you have to fail to redo it.

Despite his lack of aspirations in engineering, for Ethan, the unit was still a meaningful exercise of hard work as he commented, "I think it's still quite meaningful to me because it shows me how hard people work and what they have to do to release a product."

Finally, both Ophelia and Alan expressed that the unit was meaningful because of its implications of the real-world application of in-school learning experiences. This sentiment was perhaps best captured in this excerpt from Alan's interview: "Designing and engineering is meaningful because it helps—because it helps you know how to design stuff in the future and outside of school that could benefit people. It could benefit society, I mean." Indeed, Alan's reflection here best encapsulates the three main aspects of authenticity the students perceived in the project and the sense of meaningfulness they derived from this authenticity. That is, here, Alan describes how the PBSL unit was an authentic and meaningful engineering education experience that had implications of real-world application, especially in its real contribution or benefit to society.

Learning

Another prevalent theme centered around what students perceived they learned from the project. Within this theme, there were four sub-themes: *learning in general*, *learning about issues in biomedical engineering (i.e. arthritis and mobility challenges*), *learning about engineering*, and *learning engineering habits-of-mind* and *engineering skills*. It should be noted that while the ensuing paragraphs in this section elucidate some of the general ways in which students discussed learning about engineering, further details on student learning about engineering are presented in a later section discussing student notions of engineering. Thus, the findings presented in this section serve to more generally delineate the overarching areas of learning students experienced within the PBSL unit.

Learning in General

While all 13 student interviewees expressed that they learned from the unit, at least six (46%) students described learning from the unit in general terms. Often, this was exemplified in comments along the lines of “I learned from the project” or “I learned a lot from it” or “It was educational.” Allie, Anastasia, Ophelia, Ezra, Ethan, and Ingrid, in particular, offered such comments. It should be noted that several of these and other students elaborated on what they specifically learned from the unit throughout their respective interviews, but taken together, it seems that the student interviewees felt that the project helped them learn in general.

Learning about Issues in Biomedical Engineering

Another area of learning reported by students regarded issues relevant to biomedical engineering, specifically the condition of arthritis. At least five (38%) students indicated that they had previously been unaware of or knew little about arthritis but that the PBSL unit helped them gain a better understanding of it. Elijah, for example, expressed, “Honestly, I didn't really like, at first, I didn't know what like arthritis was and like how bad it was, but now . . . I'd like to do it again. It was pretty good; it was really fun.” For Elijah, it seems that not only did the PBSL project help him better understand arthritis, but the challenge of designing for arthritis patients resonated with him to the extent that he desired to repeat the experience.

It also seemed that arthritis was a novel topic of learning for this age group, as Anastasia observed,

> Yeah, we learned a lot of things that we probably wouldn't have learned. And, arthritis is not a very big subject that you would learn about in science class, especially in sixth grade. . . . So, it was a very different thing that took a long time, but it was actually really fun.

Here, Anastasia commented on the uniqueness of the topic of arthritis in light of what she understood to be the typical sixth-grade science curriculum; her affirmation of learning and sense of fun expressed, here and elsewhere, seemed to indicate that she welcomed the novelty of this curriculum topic and that it was engaging to her. This perceived learning about arthritis was also corroborated in the student artifacts, as seen in Figure 4.5.

Learning about Engineering

Another key area of perceived learning was learning about engineering. Twelve (92%) student interviewees indicated that the unit helped them learn more about engineering. Generally, students discussed their learning about engineering in terms of what they learned about the nature of engineering as well as the process of engineering.

Student reflections on the nature of engineering generally centered around notions or definitions of engineering or the experience of engineering. For example, Allie stated, “I learned a lot of basic engineering skills and how to think of a problem and then how to think about how to solve the problem.” Allie noted that she learned basic engineering skills, which she appeared to associate with problem-solving. Anastasia also described how the unit helped her understand the various disciplines of engineering and the different roles within an engineering design team, commenting,

> It showed me like there's like a lot of different types of engineering and how engineering—there's a lot of engineering that's just like regular, other jobs, like there's a project manager, and then there's someone else for something else, and a lot of jobs have that.

Similarly, Oscar also noted that he gained clarity as to what an engineer does, the process of engineering, and the distinctions between different types of engineering. This was inherent in his comments, quoted in the previous section, discussing students' perceptions of the unit's authenticity as it related to engineering.

Ingrid also offered some poignant reflections pointing to the multifaceted ways in which her understanding of engineering improved as a result of the PBSL unit:

> It definitely increased it by maybe even, maybe a little bit, but really like, it did increase it for like the learning experience that we had. I didn't really have that much experience with engineering. That one-day event was from—like learning about it, we sometimes did hands-on stuff like that, but this [arthritis] project really helped me understand more of engineering and the way you help people, the way you have to have plan B and a plan A; . . . and talk about leverage and stuff like that, like the leverage for the can to open was like really increasing my knowledge in like knowing about engineering. And also, how much some things [audio unclear] count, like also you might have to do things that you never thought you had to do before, like use math to measure something or use geometry to do something like that. It's like really interesting.

Here, Ingrid described having gained a greater understanding of the importance of planning and having multiple plans. Furthermore, she recognized the importance of applying and integrating mathematical and scientific knowledge in engineering design. It is noteworthy that she also associated engineering with helping people, a point that is further discussed later in this chapter.

Student dialogue around what they learned about the nature of engineering also centered on the experience of engineering. In particular, many students noted that they learned more about the complexity and effort it took to engineer something. In his interview, for example, Ethan reflected on the effort and time that it takes to engineer something:

> It changed my perspective of it from the work that they have to go through just to make one simple thing and how much something would cost to make. . . . That they have to spend hours and hours just to make a prototype and then have to spend days or weeks to get somewhat of the final project.

Similarly, Ivy noted, “I learned that it's not easy to engineer something. I learned how the design process and how, like you had to think of an idea, you had to think of what you were gonna do and then sketch all that stuff. . . . You have to get all the stuff down before you even start building and engineering it.” Anastasia echoed these reflections, saying, “Like making things is a lot harder than just drawing them out. I had to like figure out how things actually work 'cause we would draw it and then we get to the real thing and it's like, ‘how do we do this?’” As these comments indicate, it seemed that for several students, a key takeaway from the PBSL unit was a deeper understanding of the intricacy of engineering, especially the thoughtfulness and effort it takes to transform an idea into reality.

Ethan, Ivy, and Anastasia’s comments also highlight students’ perception of having learned much about the engineering design process (EDP) from the PBSL unit. In particular, students often referred to learning a great deal about the “steps” to engineering. For instance, Ivan commented: “It taught me all the—all the steps that you have to do before you actually start the project. For example, researching the things you need to order and the materials you need to order.” Ingrid also reflected on how the PBSL unit helped her better understand the distinct aspects of the design process:

> One way it changed my understanding is because when I was younger, when I used to invent stuff, like I told you, the dispenser, I wouldn't really think of like the process, the engineering process we had to do and the arthritis project—like I wouldn't think we had to do a sketch first; I would just make it, like, I wouldn't sketch it out that much. I would just like, make it, grab the stuff, see what I could build and then put it all together. But now,

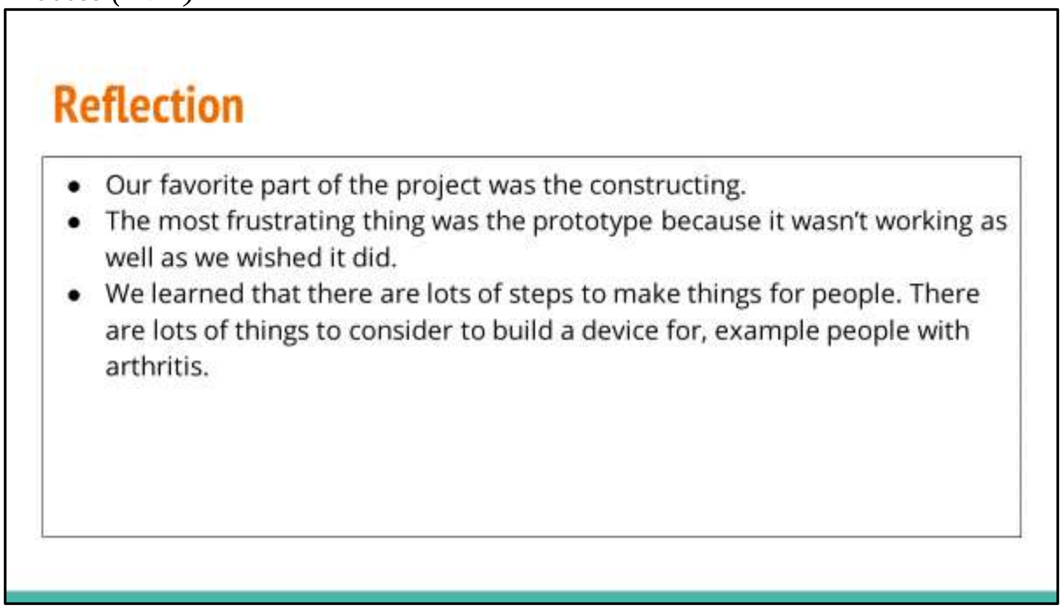
> the arthritis project has really made me think of like going through those steps that we have to go through in order to build this device.

Ivan and Ingrid both referred to specific steps they underwent in their design process for the arthritis assistive devices, illustrating that they learned that the EDP often entails various stages that build upon each other.

This theme was also present in the teams' final design and reflection presentations. For example, Figure 4.4 depicts one of the slides from one team's presentation wherein the last bullet also references the several "steps" and considerations involved in engineering design.

Figure 4.4

Excerpt of Students' Final Design Presentation Indicating Learning of Engineering Design Process (EDP)



Learning Engineering Habits of Mind and Skills

A corollary theme to learning about engineering was learning engineering habits of mind. In particular, students often commented that they learned to persist or persevere even after experiencing failure or when the design process was particularly difficult. Anastasia's reflections on her team's persistence despite experiencing failure early in the design process exemplified this habit of mind:

> Our original design, it did not—it wasn't what we ended up doing. It was kind of frustrating 'cause like it wouldn't work and then, it was when our team was not that close together. But time really helped it, and then we failed again, and then we eventually got to the design that we did, and building it was a lot of hard work. And then, we had to redo some of it.

Though Anastasia mentions multiple moments of failure and frustration during her team's design process (also noted in Figure 4.4 above), she also describes how she and her team invested hard work and persisted in their design to "eventually" get a functional design. It is also noteworthy that she highlighted that one of these early moments of failure occurred when her team's group dynamic was weaker. This notion of collaboration and teamwork are further explored in the ensuing paragraphs.

In describing what she learned about the engineering design process, Ivy also referenced experiencing failure but also retrying after said failures:

> Like, it's not, "Okay, I have a plan. Okay, let me make a blueprint. Okay, I'm going to build it." No, it's like you have to completely think it out. Then you have to, like, make a sketch; you have to think of how many parts; you have to get the parts; you have to build it. And it's not always gonna work the first time. It doesn't really work always, the first time. So, then you have to completely go all the way back and repeat it ALL over again until you can finally get it correct.

Both Ivy and Anastasia's use of words like "eventually" and "finally" suggest that their respective teams persisted in designing a viable solution. Both students also inherently described iterating as being germane to the engineering design process and to persevering in it.

In addition to persistence, the need for creativity was also implicit in students' comments. The following dialogue from Opehlia's interview illustrates this:

> *Ophelia*: I learned like how to kind of come up with something else to do when what you initially wanted to do didn't work out.
>
> *Sneha*: In terms of your design, you mean?

Ophelia: Yeah.

Sneha: Could you give me an example of when that might've happened during the project for you? Like, a specific time?

Ophelia: Well, initially we had wanted to make the claw open and close by wiring, but that didn't work. So, we like did some—we put some rubber bands to make it open and close.

Ophelia describes how her team found an alternate mechanism to achieve the same objective for their device after hitting a roadblock with their first strategy. Finding alternate solutions requires creativity in problem-solving.

Students also referenced learning some key engineering and/or making skills. As noted above, iterating was a skill several students described, as the preceding quotes from Anastasia, Ivy, and Opehlia illustrated. Other students also noted learning making skills. For example, Ezra and Ethan, in particular, expressed that learning how to sew was especially memorable. In the following dialogue, Ezra explains why learning how to sew stood out to him:

Sneha: So tell me more, you mentioned that you liked the sewing a lot. Was that something you ever tried before? Or why—how come you liked that so much?

Ezra: ‘Cause I've never done it before and I like learning new things.

For Ezra, and similarly, Ethan, the development of this skill was both novel for them and born out of the necessity of their group’s design, for which they fashioned a gripping glove. Ezra was especially enthused about learning this new skill so that on, one occasion, I observed him practicing how to sew on a piece of paper with a spare needle and thread while other members of his team had their turn sewing the glove. It is also worth noting that this team primarily learned how to sew from a peer member in the group who sewed for a hobby. Thus, the acquisition of this skill was largely peer-taught with some assistance from the teachers. While Ezra and Ethan named sewing as a specific skill they learned, other students more generally referred to learning how to “build things” or use tools.

One of Anastasia's remarks also signaled a lesson in designing for specifications and usability. When asked how she felt about designing something for someone who needed her help, she noted:

> That was interesting cause you had to look at—you can't really design it for one person if you're focusing on arthritis, and how many different types there were. It was a lot more challenging than I would think it would be, especially since like everyone—their hands are different sizes, and they have different places with arthritis, so it would affect them differently than other people.

While Anastasia's reflections here were not necessarily typical nor a common theme across students, she nevertheless made a noteworthy point in her response. Her perception of the challenge of designing within specifications but also for multiple users with different needs show that the project was demonstrative, at least to her, of this ubiquitous imperative in engineering.

Another skill that emerged as being an especially prominent area of learning and growth was collaboration (or teamwork). However, since group/teamwork was such a prevalent theme of reflection for students, it deserves a separate and lengthier discussion in the next section. It is, nevertheless, worth noting here that students' appreciation for teamwork/collaboration was both a key skill and an engineering habit of mind, which they seemed to refine throughout this project.

Teamwork and Collaboration

An especially prevalent point of student reflection was teamwork/team dynamics and lessons in collaboration. Many students reported learning how to work in a group or in a team. Yohan, for example, noted, "I learned that you can get something done when you work in a team." Interestingly, some student interviewees pointed to teamwork as being simultaneously their favorite aspect of the project as well as the most frustrating or challenging part of the project. As such, the teamwork/collaboration theme appeared to have two major sub-themes of *positive team dynamics* and *negative team dynamics*.

Positive Team Dynamics

At least seven (54%) of students commented on positive aspects of working in a team. For instance, students discussed learning to appreciate different members' strengths and contributions, synthesize different ideas, and develop a sense of mutual dependency. Ingrid, for example, explained her experience of developing all three of these collaborative skills within the context of the unit:

> Something I learned from the project is that when you are in a certain group, maybe you don't work well with that person or those group of people, but sometimes working with people you don't know can lead to, like, not knowing that this person is good and that they'll help . . . [inaudible], like getting combined is like a big experience, but we learn what ways some people do different ways and combine those different ways and made it into one way.

Ingrid's comments reflect how she learned to appreciate her fellow teammates' different approaches and strengths, though initially having some uncertainty and hesitation about how the team would get along. She also discussed how her team learned to synthesize the different approaches and ideas emergent in her group to arrive at one cohesive solution.

Oscar also independently elaborated on the skill of idea synthesis in the following dialogue sequence:

> *Oscar*: Sometimes you disagree and you agree, and you have to figure stuff like that out. And, then sometimes, you—kind of you—I mean, you can like split up and then you guys talk about it, and then you split up to do that work, and then you come back together and explain what else they can do. So, we did that a lot. And, we like, me and [William] like built the little holder wall and they were trying to figure out a better way, and then we came back together and we started talking about like what we can do better. So.
>
> *Sneha*: Do you guys think you were effective in your approach then?
>
> *Oscar*: Um, yeah because our little holder became—was—we added the little grip thing around it, so that helped. And then, we also added, on the opener, we also added the spring to help it tighten and so it was more secure. So, I think, a group really helps a lot than just an individual project.

Here, Oscar describes using a strategy, the division of labor, that helped his group incorporate different ideas, wherein members of the group subdivided into smaller partnerships to work on different aspects of their group's overall design. Oscar's reflections also point to a sense of mutual dependency in the discussions his team had on design ideas and strategies. Similarly, his comment that "a group really helps a lot [more] than just an individual project" shows a level of recognition that collaboration is important in engineering design.

William, one of Oscar's teammates, also echoed this sense of mutual dependency when asked to say more about his experiences of working in a group:

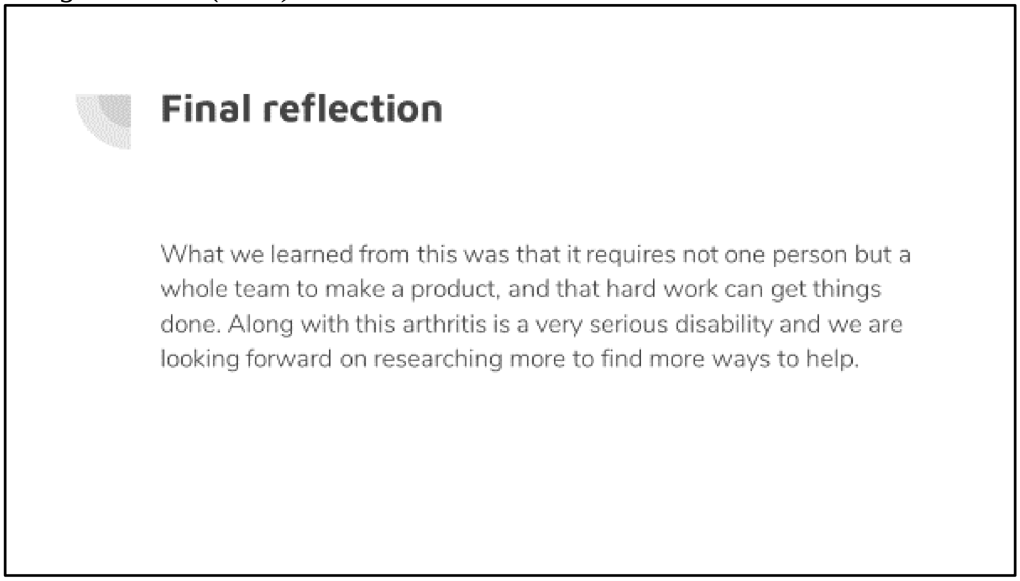
> I enjoyed it because like we like helped each other out, like, if we had a problem and then we would help that— I would like help somebody and then if I had a problem, they would help me and then so, it kept like going back and forth like that. And, I think my group—all of us worked really good together. We didn't, like, we didn't, we didn't really argue that much and we got, like, we got along with each other, most of the time.

Here, William describes a mutual helping between group members. As a result, his experience of working in a team was overall positive. It should be noted that other students, such as Anastasia, Elijah, and Ingrid, some of whom were in different design teams from each other, also described instances of mutual helping/dependence and divisions of labor within their respective groups. Thus, this team dynamic was not unique to only one design team, but seemed to emerge across multiple groups.

In a more general sense, the appreciation for collaboration and teamwork was also apparent in the students' final design presentations, as showcased in an excerpt from one team's presentation in Figure 4.4 below. This can also be seen in Figure 4.5, found later in this chapter.

Figure 4.5

Another Excerpt of Students' Final Design Presentation Indicating Learning of Engineering Design Process (EDP)



Negative Team Dynamics

Although students described ultimately learning to reconcile different or competing ideas and depending on their teammates to achieve their group's collective goal, at least six (46%) students also identified some tensions within their team dynamics. In particular, students described difficulties with disagreements within their groups and feelings of not being heard. Ingrid explained how these tensions manifested in her group:

> One of the things I didn't really like about [the project] is that sometimes we would like, not compete, not like fight, but disagree on ideas other people had, which kind of like made it difficult to choose, like what ideas you're going to put into it, [inaudible] [some] ideas were not that good and we tried to put the ideas together and figure something out. . . . Yeah, like some of the ideas weren't heard.

As Ingrid indicates, some groups had struggles reconciling competing ideas which left some students feeling unheard. Yohan, who was assigned to a different design team, also shared this sentiment about teamwork when he commented, "I liked like working like together on it. Yeah. And then the thing I didn't really like was some of my teammates like kind of, they didn't really listen to my ideas." Interestingly, although Yohan overall seemed to like working as a team, his greatest frustration was also feeling unheard, at times, by his teammates.

Team disagreements not only arose from competing ideas but also coalesced around role assignments. For example, Alan alluded to his frustrations about which tasks certain members got to perform: "Well, I didn't like how the people [his group members] argued about which position to get. It kind of makes you make decisions about who gets to do the cool stuff and the kind of very boring stuff." Ivy, one of Alan's teammates, also described moments when other members of the group could "kind of take charge" and become "the boss of stuff and kind of like take it over." Thus, some team tensions arose from perceived unequal distribution of group roles and responsibilities.

Agency

One important theme emergent across eight (62%) of the student interviews reflections was a sense of agency. Students articulated this agency in terms of helping others. For example, in this dialogue sequence, Yohan expressed that he now feels like he can help others:

> *Sneha:* Did your participation in the PBSL unit impact your sense of meaning or purpose in life?
>
> *Yohan*: Yes, because I know I can help people now . . . that are outside in the community.
>
> *Sneha*: And why is helping people—nowing that you can help people important to your sense of purpose and meaning in life?
>
> *Yohan*: So that I can keep on helping people, if they need it.

Here, Yohan indicated that the PBSL unit was influential in helping him recognize that he has the ability to help within and contribute to his community. Similarly, Alan noted, "It [the PBSL unit] helped me do something [to] help other people 'cause it inspired me to do something about—just do something about poverty and like global warming which can have pollution, air pollution which can kill people." For both Yohan and Alan, the project not only gave them a sense of agency within the context of helping arthritis patients, but they seemed to develop a sense of agency in serving the community beyond the specific context of the unit itself and into the wider community or wider societal concerns.

This sense of agency in helping the community was also tied to engineering for some students. For example, Allie responded to the question on the unit's impact on her sense of purpose in life stating, "Yes, it did because I guess learning and being able to know that I can help others this way and giving back to people by engineering and doing the project that we did was really nice to know that I would be able to do that." Here, Allie explicitly tied her sense of being able to give back to others to engineering. Furthermore, she identified the project as being influential in helping her recognize that. As quoted earlier, Ingrid's response to this same question also echoed similar sentiments and inherently indicated a sense of agency when she noted:

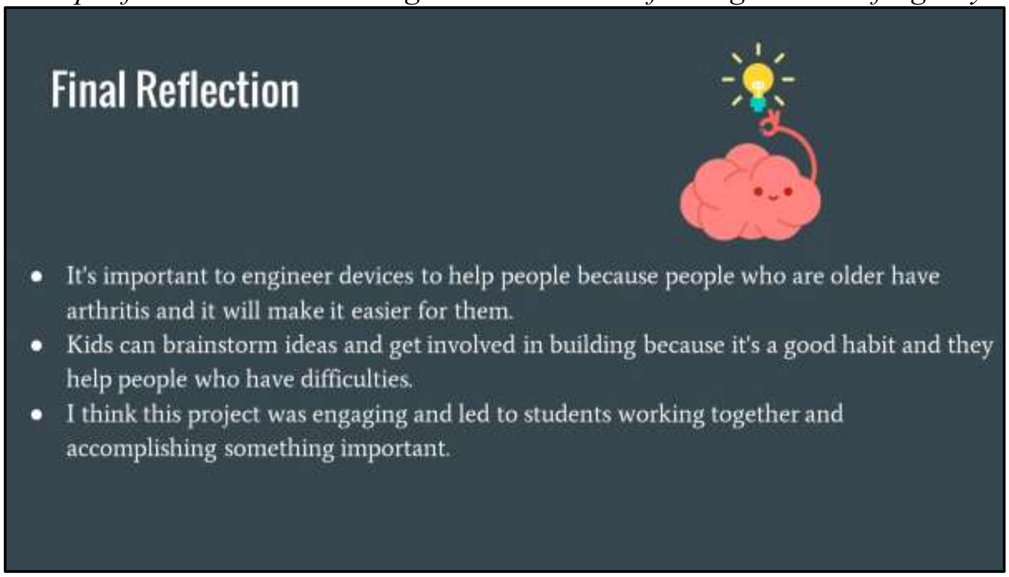
> It did because when I was engineering that device, it really helped me think of how I could help people in the world. . . . I'm like, "This small device can impact a lot of people like to help them." . . . I wasn't, like, thinking of being a doctor until I started that device and saw how small things and can help impact a big community of people.

Although Ingrid indicated that the project inspired her to pursue medicine in the future, she nevertheless stated that it was engineering the arthritis assistive device that inspired her to think of the potential ways she could help others and impact her community. Her appreciation of how "small things" could have a big impact also points to a sense of agency in that she recognized that she could effect change in "small" ways.

Agency was also present in the students' final design presentations. As shown in Figure 4.6, one team reflected on the possibilities and ways students could help engineer solutions for people in need within their communities.

Figure 4.6

Excerpt of Students' Final Design Presentation Reflecting a Sense of Agency



In this sample artifact, both the second and third bullet points discuss how "kids can brainstorm ideas and get involved in building" and "accomplish something important."

The most compelling indication of a sense of agency within the aforementioned student comments and this sample artifact was the use of words and language like, "I can," "I could help" and "I could do something about." The use of these terms of ability, especially in conjunction with references to "kids" or students' use of first-person pronouns, suggested that students perceived themselves as being agentic in their ability to help others and their communities.

Student Perspectives on Purpose-in-Life

As noted previously, the interview protocol also elucidated student perspectives on purpose in life, both generally and personally. As such, student responses generally centered around three major themes: *notions of purpose-in-life*, *student purposefulness,* and *career aspirations*. The first theme, *notions of purpose in life*, describes students' notions of what having a purpose in life meant to them in general terms. *Student purposefulness*, on the other hand, refers to how students reflected on their own sense of purpose in life and the types of purpose they identified for themselves. Finally, in the context of purposefulness, the *career aspirations* theme encompasses the prevalent priorities that guided students' career goals, which were and were not purposeful in nature.

It should be noted that several of the sub-themes within these three major themes seemed to overlap with each other. For example, career and professional aspirations were relevant to each major theme but were nuanced in the ways in which they emerged within these three broader aspects of students' perspectives on purpose in life. Similarly, social purposefulness was also a theme that underscored multiple components of the purpose-in-life segment of the interviews, and students' comments centered around social purpose both in general and personal terms. As such, there is likely much intersection and interrelatedness between the themes presented in this section.

Notions of Purpose-in-Life

The *notions of purpose-in-life* theme refers to students' general understandings of the concept of a purpose in life. More specifically, this theme encompasses students' responses and reflections to the interview question: "If I say the words, 'purpose in life,' what does that phrase mean to you?" Given the age (between 11 and 12 years of age) of the students, it was important to ask this question because it elucidated whether students had notions of this concept at all, and if they did, the specific frames of reference or definitions they held with regard to it, as those notions likely influenced their own sense of purpose in life.

Although a few students were either unsure of what the purpose-in-life concept meant or struggled to articulate what it meant to them, the students who did offer a definition generally had notions that fell into what could be collapsed into three sub-themes: an existential reason, a beyond-the-self contribution, and a vocation or a calling. Again, students' notions of purpose-in-life did not necessarily fit any one category neatly, but rather they seemed to reflect one or more of these descriptions.

An Existential Reason

At least four (31%) students described the concept of purpose-in-life as a reason for one's existence or life. Students referred to this as having a "reason" or a "part" in life. For example, Ivy reflected,

> The phrase "purpose in life . . ." what it means to me is like anybody that has a purpose in life, everybody's here for a reason, like, like people like in history, they were, they were here, they had their reason in life . . .; it was their purpose.

Similarly, Alan commented, "It means like what your purpose is in life. It's kind of like—it means like what you do in the world, like you have a part in the world, that you're not alone, you got other people . . . and everyone has their part in the world." For these students, having a purpose in life appeared to be a universal facet of being and something that everyone intrinsically possesses. Furthermore, implicit in this notion of purpose-in-life as a reason for being and living is that this reason is not merely significant for the individual but that it has implications for the broader fabric of society.

A Beyond-the-Self Contribution

At least six (36%) students conceptualized purpose-in-life as one's potential contribution to the world. For example, Oscar responded that he thinks of a life purpose as being "probably like what you think your part in life is going to be. So, like . . . what you're going to do in the world. How you're going to change stuff." Ophelia offered a similar definition, saying "It kind of means like what somebody has done to make a difference." These notions of purpose-in-life as the ways in which one might change, impact, or contribute to society aligns with the beyond-the-self component described in the purpose literature (Bronk, 2014; Damon et al., 2003). Thus, these definitions of purpose-in-life essentially espouse a beyond-the-self contribution.

A Vocation or Calling

Three (23%) students also talked about purpose-in-life in terms signaling a sense of a vocation or a calling in life. Ethan, for example, described purpose-in-life as "what I am meant to do in my life and what I need to accomplish during it." Ethan's use of language like "meant to do" indicated a sense of a vocation or calling that he is destined to fulfill. Ingrid spoke in similar terms, using words like "supposed to be" to describe her understanding of purpose-in-life:

> [It's] like what am I supposed to be, like I'm supposed to be . . . like my future job. Like, it's my purpose. It's what I think when I see "purpose in life," like what job I'm supposed to have and why and how it helps the world and how I could change things in the world. And also our purpose in life—I'd like to be a good person, also; that really counts. That's what when I think of that.

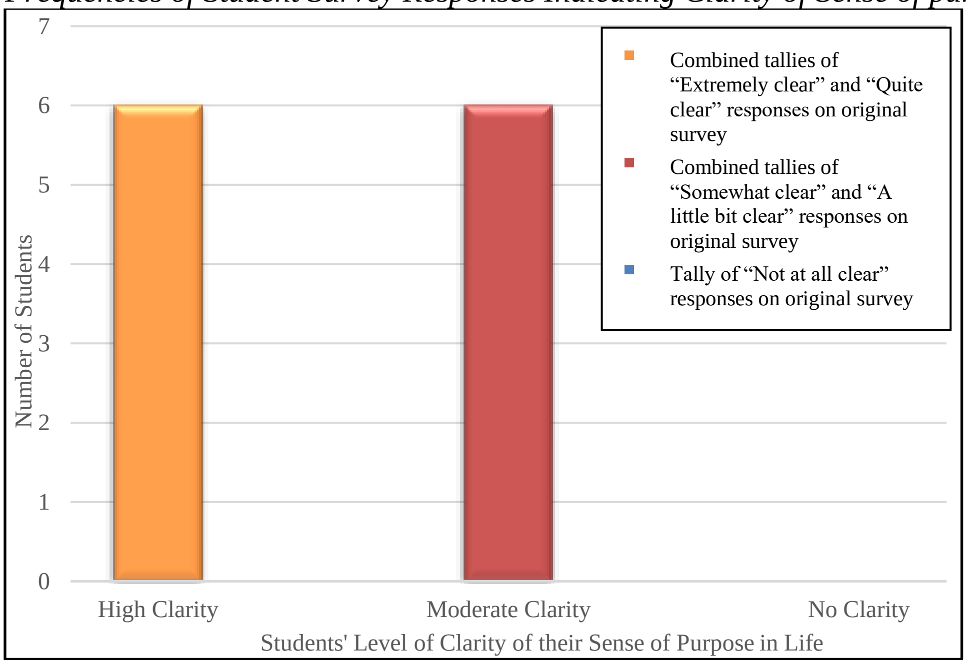
Here, not only did Ingrid's comments indicate a sense of a vocation, but she saw this vocation as being intertwined with her future career or profession. That is, her sense of a calling in life would be manifest in the future profession she would occupy. Ingrid was not alone in conceiving of one's purpose in life as intersecting with one's career; this notion was also an underlying assumption in other students' reflections, particularly when they discussed their own sense of purpose in life. It is also worth pointing out here that Ingrid considered career to be an important facet of one's—especially her—purpose in life because she sees that as the way in which she will be able to make a beyond-the-self contribution to the world. Of course, Ingrid also had a broader underlying component to her notion of purpose-in-life in citing morality as being fundamental to having a sense of purpose in life. It should also be noted that the notion of "a calling" or a vocation in life is common in Catholic parlance; it is therefore possible that students' association of purpose-in-life with these notions may be influenced by the religious context of the school, wherein such concepts are discussed.

Student Purposefulness

One objective of the interview protocol was to gauge whether students had their own sense of purpose in life and if they did, how they described the purpose(s) of their lives. As such, the interview protocol included a series of questions to elicit student reflections regarding these points. Given that the student participants were in their pre-teen years, several of them had developing sense of purpose in life, with some students beginning to articulate a sense of their purpose while others were still somewhat unsure of their purpose in life. As an indication of the general spread of students' clarity in their sense of purpose in life, Figure 4.7 shows the combined results of student responses to the survey question: "How clear is your sense of purpose in life?" The mean for this survey item, which originally had a five-point Likert-type scale (with a scale of 1, "Not at all clear," to 5, "Extremely clear") was 3.58, suggesting that on average, the participants had at least a moderate level of clarity in their sense of purpose in life.

Figure 4.7

Frequencies of Student Survey Responses Indicating Clarity of Sense of purpose in life



As noted in the previous chapter, the analysis for the student purpose component of the interview used Bronk's (2014) purpose typology. Bronk identified five main types of purpose: religious purpose, familial purpose, professional purposes and callings, artistic purpose, and civic and political purpose. Since Bronk's explanation of civic and political purpose paralleled Ford and Smith's (2007) description of social purpose in that both described a sense of altruism, service, or concern for others, I considered civic and social purpose as being synonymous with each other. Under this coding schematic, then, students seemed to most prevalently indicate a sense of civic/social purposefulness and/or a professional purpose or calling. Some students were unsure of their purpose in life, while others identified miscellaneous types of purpose that fit the other three categories of purpose (religious, familial, or artistic purpose), though not quite as saliently. The ensuing discussion parses out how these different types of purpose emerged across the student interviews.

Civic/Social Purpose

Making civic or social contributions was a common theme of students' sense of purpose. During their interviews, at least 11 students (85%) discussed their sense of purpose in life in socially purposeful terms, often in the context of helping others. For example, Allie stated, "I feel like my meaning is to be there for other people and to like help some other people and have like a sense of being there for someone when people aren't able to be with them." Elsewhere in her interview, she elaborated on why helping others was important to her, saying, "It is really important to me [to help others] because I want to give back to others and to the community for what they've given me and provided me." Allie's social purpose to help others thus appeared to derive, in part, from a sense of gratitude and/or obligation to "give back" to her community because of the support she felt she received from it.

Although he indicated his sense of purpose in life was still developing, Alan also discussed his purpose as being tied to helping other people. In the following dialogue sequence, Alan reflected on this:

> *Sneha:* Do you think you have a sense of your purpose in life? . . .
>
> *Alan:* Umm, I have one and it's like I'm still deciding what I should do and what I should do to help other people in the world and yeah, I'm deciding still on what job would fit it.
>
> *Sneha:* . . . In terms of your purpose in life, you said what you should do to help other people in the world, so do you think that helping other people in the world is part of your purpose in life?
>
> *Alan:* Hmm mm, yeah—like help other people and help make them successful just like me.
>
> *Sneha:* And why do you feel like that's your purpose in life?
>
> *Alan:* Because I want to help other people and I want to care, help other people. I care about them. I want to do that because I want everyone to have just opportunities like I have and everyone deserves an opportunity to get a good job and stuff.

Though Alan was still discerning his purpose in life, he nevertheless believed it was ultimately linked to helping others in some way. Furthermore, his sense of social purpose was driven by his care and concern for others and a value for the equitable treatment of others.

Ingrid also articulated a sense of social purposefulness. Ingrid relished the possibility of positively impacting others, saying:

> In general, helping people, to me, is important because I impact them. Like, even though if I don't know them, like, I didn't really know the people that we helped for arthritis [project], like [Allie]'s dad, um, I really felt it's important to do because I know I'm impacting them in some big way, especially if I help them with something that they really, really need help in.

For Ingrid, knowing that she could potentially impact another person’s life, whether she was personally acquainted with them or not, was significant and meaningful to her. Her words here also indicated a sense of agency in the realization that she herself could help others in her community. Furthermore, she seemed to value this agency, recognizing its importance and potential for impact.

Student responses on the post-unit survey also showed trends of socially purposeful inclinations. As seen in Figure 4.8, the majority of the student interviewees at least occasionally hoped that they could make a meaningful contribution to the world or impact it positively. The mean for the original five-point Likert-type survey item (with a scale of 1, “Never,” to 5, “Almost all the time”) was 3.75. Similarly, in responding to the survey item inquiring, “How important is it for you to make the world a better place in some way?”, the majority of students selected a response indicating that doing so was very important to them. The mean for this five-point Likert-type item (with a scale of 1-“Not at all important” to 5-“Extremely important”) was 4.08.

Figure 4.8

Frequencies of Student Survey Responses Indicating How Often They Hope to Make a Meaningful Contribution

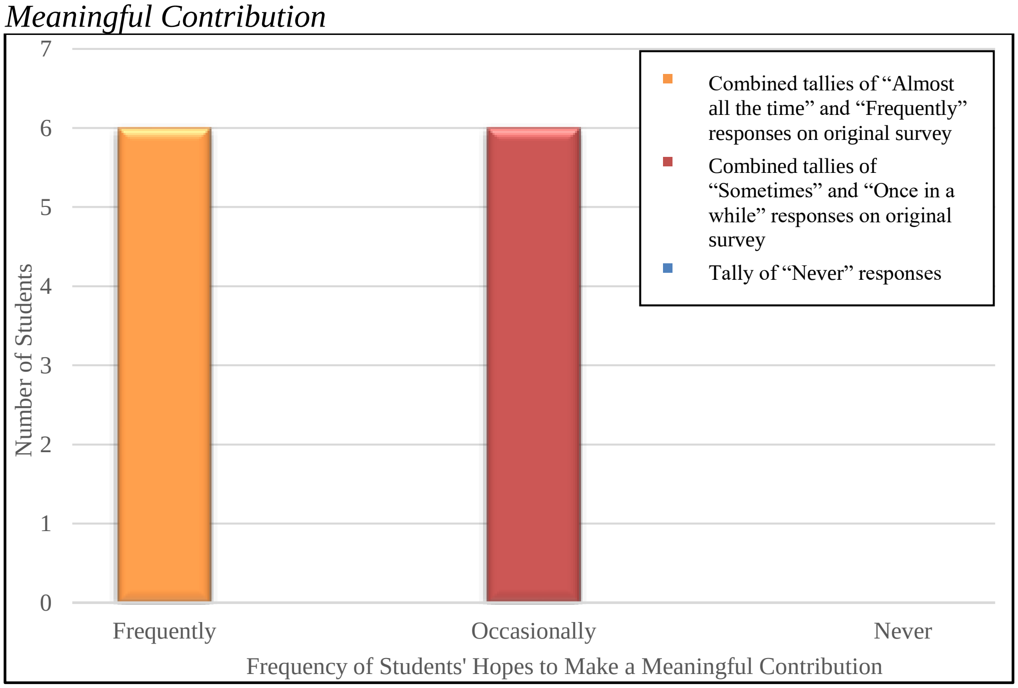
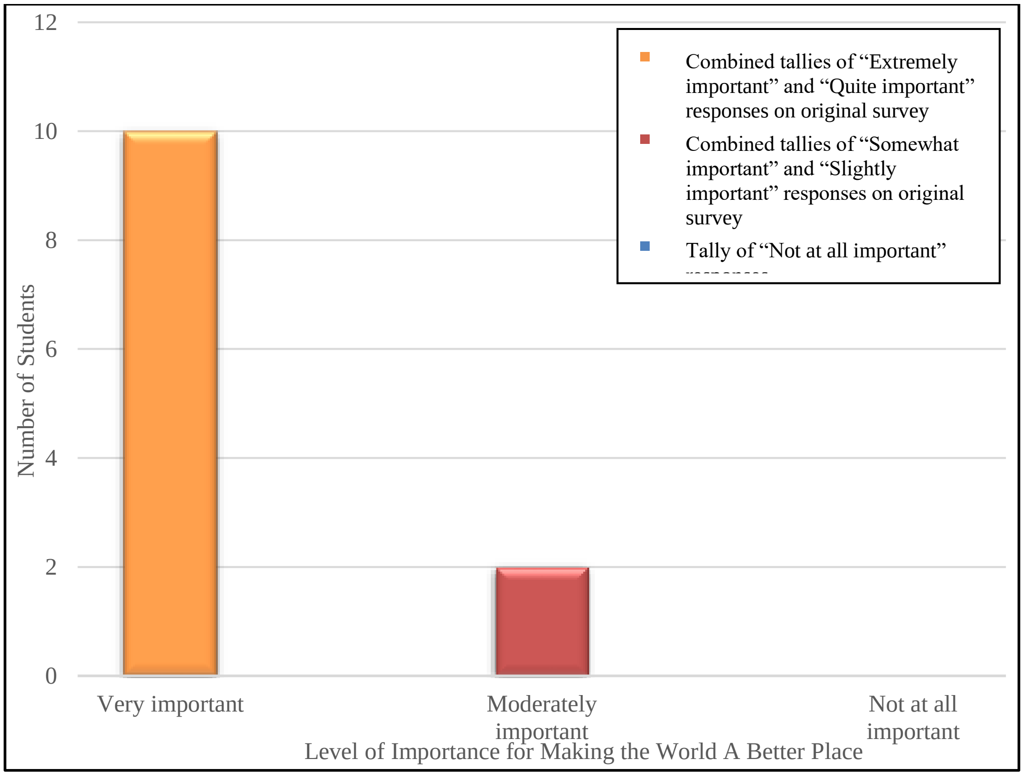


Figure 4.9

Frequencies of Student Survey Responses Indicating Personal Importance of Making the World a Better Place



Professional Purpose or Calling

At least six (46%) students described their sense of purpose in life in the context of the professions or careers they wanted to pursue. For example, when responding to the question inquiring about his sense of purpose in life, Ethan said, "I think I have an okay understanding of what I want to do in my life and what I want to pursue as a job. I think my purpose in life is to be an entrepreneur." For Ethan, being a future entrepreneur was inextricably linked with his sense of purpose. Later in his interview, Ethan also explained his profession as being a means of helping people when explaining why helping others is important to him, "It's very important because if I see someone that is less fortunate as me, I would want to help them have a better life and give them advice on what to do. . . . Oh, because I want to be an entrepreneur, I—for my company, I'd like, to help people that need food, need clothes and other things and help the community out with those things." Thus, Ethan's professional purpose was also tied to a socially purposeful component.

Similarly, Ingrid also contextualized her social purposefulness in terms of her career aspirations:

> I feel like, a purpose, not like right now, but when I grow up is to like help people and like animals that need help and stuff. . . . Well, I mean, like being a vet is like, what I think my purpose in life is like THAT job or being like a doctor to help people, or being a pediatrician or something like that.

Ingrid saw her future profession as being the vehicle by which she would be able to help people or animals.

Some students described their purpose in terms of an occupational "calling." William, for example, seemed to think of his sense of purpose in life in terms of a "vocation," as he reflected here:

> Well, I'm still like 12; I'm still pretty young, and I still have a lot of time to like to like have a vocation. . . . Well, it could be—I could have a vocation in the Catholic life, maybe because I do go to—I go to Catholic school, I am an altar server, and I go to Mass every single Sunday.

Though William was still somewhat unsure of his personal "vocation" or calling in life, he had considered the potential of entering the priesthood, which, as referenced previously, is often referred to as a "religious vocation" in Catholic parlance. Similarly, Elijah also indicated his potential desire to be a priest, when asked if he had a sense of his purpose in life. Since priesthood and the religious life inherently entail a significant spiritual component, the communities served by priests do not view the priesthood as a typical occupation but rather, more as a "calling" from God. Thus, for both William and Elijah, their potential inclinations toward the priesthood derive from a sense of a "call," or a "vocation," though there is a professional aspect to it as well. The sense of a "calling," however, also extended beyond students who were considering religious occupations; for example, Ethan and Ivy's reflections on their purposes-in-life also implied a sense of "calling" to the potential future careers they identified for themselves.

Miscellaneous

While several students identified a sense of civic/social purpose or a professional purpose or calling for their lives, at least eleven (85%) students identified other purposes in life, in addition to or separately from the aforementioned types. Students spoke of an assortment of purposes, including those centered on familial purpose, artistic purpose, adventure and fun, and religious purpose. Allie, Ivy, Yohan, and Ethan discussed familial purposes, typically talked about in terms of taking care of and "being there" for their families and friends. Students with an artistic purpose, such as Ophelia, discussed the importance of having opportunities to do art and be creative in their lives. One student, Anastasia, said that she would probably find purpose in life by leading a fun and adventurous life filled with travels. A few students, such as William, Alan, and Elijah, also identified religious purposes. For example, when asked how important helping others was to his sense of purpose in life, William responded,

> I think it's pretty important because I'm helping others like giving the food to the homeless. And like in the Bible, it says if you if you do certain things, then you will be more holy—holier and with God.

For students like William, helping others aligned to his religious beliefs and fulfilling a sense of religious purpose.

Unsure

Although several students were able to identify a definitive purpose in life and many students were able to articulate at least potential purposes or goals that were important to them, at least seven (54%) were still somewhat unsure or hesitant to articulate one specific purpose in their lives. Ezra, for example, was quite unsure as to how to respond to the question, "Do you have a sense of your meaning or purpose in life?" This uncertainty might likely be due to the age of the students, who themselves noted their youthfulness with regard to having a defined sense of purpose in life. For example, Anastasia noted “Uh, not yet. I feel like you have to be older for that.” Similarly, as William and Alan indicated in some of their responses quoted above, students often felt that they were still young and still had time to develop a clearer sense of purpose in life. Nevertheless, generally students recognized that though they were unclear as to their purpose in life, they would discover one as they grew older.

Career Aspirations

The interview protocol also included questions regarding students’ career aspirations and what they looked and hoped for in a future career. More specifically, students responded to two questions intended to shed light on their perspectives concerning the priorities in their career aspirations: 1) “In the future, is it important to you that you study or work in a job or career that brings meaning and purpose in your life?” and 2) “What sorts of things are important to you in your future job or career?” Student responses tended to center around three main priorities: *social purposefulness and sociability*, *security and stability*, and *fun and engagement*.

Social Purposefulness and Sociability

At least four (31%) students identified priorities of social purposefulness and/or sociability when discussing their hopes for their future careers. For example, Ivan, who had future engineering aspirations, identified helping people through engineering as being important to him:

> So, when you're an engineer, you, you study and maybe make new inventions that can help people in their daily, like daily lives. . . . So, what is most important in my, in my, in my future job is—what will be my future job—well, I hope— is to invent new things that can help people, for example, technology that can open automatically open the door for someone.

As his comments suggest here, Ivan was drawn to engineering because of the ways technologies can help solve peoples’ problems. Alan shared Ivan’s sentiments and also discussed how being an astronaut, a computer engineer, or an electrical engineer could potentially introduce technologies or discoveries that could "change the world."

The potential to impact people in a large scale was also important to Ingrid. When reflecting on what having a successful career would mean or look like for her, Ingrid said:

> It's very important to me to have a job that makes me feel like I have a purpose in life, where also I feel what I want to feel like, like a grownup. . . . I'm really focused on getting that specific job or like helping people. . . . I feel like having a successful career is like important to me, like really important, because then if I have a successful career, I can help more people. Like, it's like not just what we did right now, with the arthritis project; we did help people, but maybe one or two people. . . . But having a successful career is important to me because it like helps my mind, like the mindset of engineering, or having a specific career to develop something big, like maybe [an] orphanage or something like that helps people like that big development of something.

Ingrid's career aspirations was thus highly driven by the potential impact she could have. Elsewhere in her interview, Ingrid also discussed that it was important to work with and around people because of the sense of shared experiences such environments can provide. Allie, who wanted to be an orthodontist, shared similar sentiments saying,

> I feel like what's important to me are the people around, like my coworkers or friends and the people that come in and need help that I can help. . . . Cause like I feel like, um, being able to help them is an important job and being able to know that you did something for them that maybe someone else couldn't do.

Thus, both Ingrid and Allie, among others, shared career aspirations that prioritized not only the ability to help others, but also the ability to interact and foster positive relationships with their future colleagues. In this sense, they seemed to prioritize social purposefulness and sociability when thinking about their future careers.

Security and Stability

At least three (23%) students identified security and stability. Students talked about finding careers that would likely offer them a financially secure and stable job that could help them achieve and sustain a comfortable quality of life. William, for example, explained this when explaining his college aspirations:

> I kind of want to go to college, hopefully. And people—like people say that college like gives you like a 50 or more percent chance of like a better life. And, if you have a degree, you can like get easier jobs and hopefully, like good paying ones.

He went on to further elaborate that a well-paying job would likely assure him of being able to afford a good house and help take care of a family, should he get married and have children in the future.

Ophelia echoed William's line of reasoning, indicating that in addition to having a fun job, she wanted a job that paid well enough for her to live comfortably and well. While neither William nor Ophelia necessarily identified one specific career to which they were committed and which they believed would provide this sense of financial security and stability, Ophelia did identify various careers in engineering, chemistry, or veterinary sciences as being potential careers that might meet these priorities. Thus, while students, like William and Ophelia, may not have committed to a specific career that could meet these priorities, they seemed to be aware of the implications of earning potentials to one's future quality of life. As such, an occupation's earning potential and its promise of security and stability were beginning to weigh more heavily as students began to consider potential career options.

Having A Fun and Engaging Career

Three (31%) students also said that they wanted their future careers to be "fun" and generally engaging. For example, Anastasia said: "I wanna have a job that's fun and that I can enjoy, and then work at the same time." Other students described careers that aligned with their interests and what they enjoyed doing. Yohan, for instance, said that he would like to do "really anything to do with like cars or something," because he has always had an interest in cars and racing cars. Similarly, Oscar, who enjoys art and has always had an interest in engineering, indicated that he wanted a career where he could do art and design and build things. For these students then, it was important that their future careers align with their interests and provide a sense of fun and engagement.

Student Perspectives on Engineering

The third objective of the interview protocol was to understand student perspectives on engineering, including their conceptions of it and their interests and aspirations, or lack thereof, in engineering. This segment of the interview was primarily aimed at understanding student perspectives of engineering in broad terms, both as it related to the PBSL unit and, even more so, beyond it. Student responses from this portion of the interview could be categorized into two broader themes: *engineering notions* and *engineering interests.* The *engineering notions* theme encompasses the various student conceptions of engineering. The latter theme, *engineering interests*, refers to the aspirations (or lack thereof) and the reasons students cited for being potentially interested in studying or pursuing an engineering career.

Engineering Notions

Students' notions of engineering indicated how they conceived of engineering, both by way of definition and in terms of the general endeavor or profession. These responses generally arose in the context of questions inquiring after student's own definitions of engineering and whether or not they viewed engineering as a career that could help the community or bring one a sense of purpose in life. Students appeared to conceive of engineering in four main ways: engineering as embodied in the *engineering design process*, engineering as *making and inventing*, engineering as *problem-solving*, and engineering as a *socially purposeful endeavor or profession*. Like many of the other themes discussed throughout this chapter, there was much overlap in these sub-categories of engineering notions. That is, many students thought of engineering as a problem-solving design process to make or invent something to help others or benefit society, thus encompassing one or more aspects of the aforementioned conceptions of engineering.

Engineering Design Process

Paralleling the findings regarding student perspectives of the PBSL unit, at least seven (54%) students associated engineering with a methodical design process. For example, when asked to explain what engineering is in her own words, Allie offered this definition: “Engineering is planning and like coming up with a solution to a problem that you found, creating something for that solution, and testing it and rebuilding and re-creating and testing until you come with the product at the end.” Similarly, Alan responded to this same question by alluding to the scientific method and then describing various aspects of the process:

> Engineering is . . . the concept is like it makes you build stuff, . . . it's kind of like building stuff and getting ideas and . . . doing the STEM, kind of following the scientific method in a way. And you can build stuff and improve them . . . and planning, and the planning phase. It's like that . . . the engineering phase . . . the one we talked about in school in the arthritis [project], it's like that.

In both of their definitions of engineering, Allie and Alan named and listed various stages typically identified in various models of the engineering design process (EDP), including a planning phase, a testing phase, and an improving or iterating phase. Thus, students like Allie and Alan appeared to think of engineering as an active and methodical process that ultimately led to the creation of something, namely a solution, as Allie indicated in her response.

Making and Inventing

Another common definition of engineering, offered by 11 (85%) students, centered around “making” words such as “inventing,” “building,” or “creating.” For example, Ezra, Elijah, and Yohan defined engineering simply as “making something” or “building something.” Ivan similarly noted, “In my own words, engineering is creating something with technology or without technology." Of note in Ivan's definition is his association of engineering with technology and the role technology can play in this act of creating.

William also thought of engineering as making something, though he defined the general aims to which this making was directed: "I think engineering is like where someone either like makes something or they have like—they're good at something and they make something that either help somebody or like benefits to the world, like people just get use from it." William's notion of engineering, then, is making for the purpose of helping others or benefiting society. In this sense, William appeared to have a socially purposeful notion of engineering too, in that he saw engineering as having a prosocial orientation.

Ophelia seemed to think of engineering as entailing a level of synthesis. While discussing some of her past extracurricular STEM and engineering experiences, Ophelia distinguished engineering from playing with or using technology, as her comments in the following dialogue sequence showed:

> *Ophelia*: I guess playing with technology too. 'Cause at the STEM camp, I did a class thing that they just called it engineering, but it wasn't quite engineering cause we designed and printed 3D-printed things, whatever we really wanted to.
>
> *Sneha*: Okay. So that's an interesting question. What, why was that, in your mind, less engineering and from what you know engineering to be? So why was that technology versus engineering?
>
> *Ophelia*: Um, cause it didn't really involve putting things together all that much. It was mostly just designing something on a computer and then putting the hard drive into the 3D printer and having it 3D print.

By alluding to "putting things together," Ophelia perceived engineering as involving either the synthesis of ideas or different material components as opposed to the mere transcription of an idea from a digital or visual concept into a physical, tangible one.

Problem Solving

Like Allie's comments cited above, other students seemed to talk of engineering in terms signaling a level of problem-solving. For example, while discussing some of Yohan's survey responses with him, I asked Yohan to elaborate on a survey response in which Yohan indicated that designing something to solve someone's or a community problem was quite meaningful to him. Yohan elaborated on this point, saying, "So, like, you could engineer something that could solve any problem."

While other students did not necessarily reference problem-solving, their definitions nevertheless seem to inherently describe problem-solving. For example, Ivy described her notions of engineering in the following way:

> Engineering is like—like when I think of engineering, like I think the building [inaudible] but building for a cause, like we did for arthritis, and like engineering, like robots, and like computers and like phones, that's one of them. And, some also ties in with like the helpful stuff. Like, isn't like robotics, like when somebody loses an arm, they get like a robotic part, sometimes; that also pops into my head, when I think of engineering.

Ivy's definition of engineering here names several problems or issues for which engineering has offered a solution. For example, she notes the invention of robotic arms for patients who needed to undergo an amputation. Of course, she also references the struggles of arthritis patients that was at the center of the PBSL unit. Furthermore, she like William, also conceived of engineering as being oriented toward a cause. While some of these causes included general problems, such as communication, others she somewhat ambiguously described as being related to "the helpful stuff."

A Socially Purposeful Endeavor and Profession

As a few of the aforementioned examples of student definitions of engineering have already illustrated, one especially salient student notion about engineering was that engineering was or could be a socially purposeful endeavor and profession. This was evident in all 13 (100%) student interviews. Every student interviewee spoke of engineering as actually or potentially contributing to society, impacting the world, or helping others. For example, when asked to define engineering in her own words, Ophelia offered this definition: “It's something that kind of makes the world better … and you get to build stuff.” Ethan also defined engineering in similar terms, saying, “Engineering is building or making something to do something good, usually in the community or to help someone. [Short pause] Or it can be like a new invention, like again, software engineering for iPhones and that stuff.” As Ophelia and Ethan’s definitions, along with those of Ivy and William’s above, show, students seemed to think of engineering as being an endeavor inherently oriented toward making positive contributions to society or the community.

This was also evident in Ingrid’s notion of engineering, which appeared to be especially influenced by the experience of the PBSL unit:

> Engineering, to me, is helping create something that's going to impact the community or even the world in a big problem. Like for example, the arthritis was a big problem in our community. Helping develop that [device] was like engineering to me and seeing how it helped people, I really liked thinking of me being successful in what I engineered and what I created to help the community.

Not only did Ingrid use the word “helping” several times while defining her notion of engineering, but her definition was also personalized. By noting, “I really liked thinking of me being sense of me being successful in what *I engineered* and what *I created to help the community*,” Ingrid indicated of sense of agency in her perception of herself having engineered something that contributed to her community.

Another important finding was that even if students did not necessarily have strong engineering aspirations or engineering interests, students still perceived engineering as a potentially socially purposeful profession. When asked whether they could see engineering as a career that could bring them or others a sense of purpose in life, almost all students seemed to agree that it could. For example, Allie, who had aspirations to be an orthodontist, responded with this:

> I feel like engineering can bring meaning and purpose to life because maybe like someone isn't quite sure what they need to do in life but then once they go into engineering, they understand like, “Oh, I can help someone with something that's hard for them, or get some people places where like maybe wouldn't get to without my help or engineering in general.”

Allie’s reflections here indicate that while she may not have aspired to be an engineer, she generally viewed engineering as being potentially socially purposeful because of the possibilities it offers to help people with their problems.

Similarly, Ethan, who, as noted before, was quite committed to being an entrepreneur and as a result did not have a personal interest in engineering, also recognized how engineering could be socially purposeful and how engineers could contribute to improving communities. In the following dialogue sequence, Ethan explained his views:

> *Sneha:* Do you see engineering as a career that can help bring you or maybe others a sense of purpose in life? Why or why not?
>
> *Ethan*: Um, yes. As in poor countries like Haiti, um, a lot of places like have rivers that they have to cross and sometimes it's too deep and they drown and they need a bridge. So, engineers build the bridges for them, that could give inspiration of people that would want to do that.

Despite his own lack of interest in pursuing an engineering career in the future, Ethan’s concrete example of bridge-building in economically disadvantaged communities showed that he had an understanding how engineers could find a sense of social purpose in the work that they do.

Engineering Interests

During the interview, students’ engineering interests were apparent in their discussions of their engineering aspirations, or lack thereof, and why they were or were not interested in engineering. For some students, these interests may have been preexistent or influenced by other experiences with engineering; for other students, these interests were partly influenced by their participation in the PBSL unit.

Engineering Aspirations

The *engineering aspirations* theme refers to students' interest in potentially studying or pursuing an engineering career in the future. Although in the interest of brevity, this discussion will not detail each student's inclination toward an engineering career, Table 4.1 near the beginning of this chapter summarizes each student interviewee's engineering interest and future career aspirations for the reader's reference. Collectively though, students' engineering aspirations could be considered relative to their participation in the PBSL unit; that is, students either had or did not have preexisting aspirations in engineering, and after the unit, these aspirations may have changed.

Preexisting Aspirations. To determine how previously inclined or interested students were in pursuing an engineering career, the interview included this question: "Before [the arthritis project], did you want to be or think about being an engineer?" Student responses either indicated that they had preexisting aspirations, were ambivalent about engineering, or did not have engineering aspirations at all.

About nine (69%) students seemed to have at least some preexisting interests and aspirations in engineering to varying degrees. For some of these students, such as Oscar and Alan, their aspirations in engineering were enduring in that they first formed these aspirations in their early childhood. For example, Alan explained why he wanted to be an engineer saying,

> I always wanted to be an engineer. . . . Because it just was fun—it was fun. It's fun to be one because you get to be part of building projects and you get to make—do inventions and invent stuff that are helpful to the world, to society.

As his comments indicate here, Alan aspired to be an engineer since he was young and his chief reasons for this aspiration were that he found enjoyment in engineering and the potentially socially purposeful contributions he could make through engineering. Notably, these reasons aligned with Alan's general career priorities of helping others through his occupation, as discussed earlier.

The other four (30%) students either did not have preexisting engineering aspirations because they had already decided on different careers or they were ambivalent in that they had not much thought about engineering or their general career aspirations before. For example, when asked whether he had considered becoming an engineer prior to the unit, William responded, "No, not really because—I don't know—because I wasn't really, like, focused, or I wasn't really thinking about anything, like anything of like my future." Given their young age, it was fairly expected that some students, like William, had not yet reflected on their future careers or had yet to commit to a particular professional aspiration.

Post-unit Aspirations. To gauge whether students' engineering aspirations had shifted after their participation in the PBSL unit, the post-interview protocol also asked whether students wanted to study engineering or pursue an engineering career in the future after the unit. Eleven (85%) students indicated increased interests in future career aspirations in engineering. Though the question was not phrased to directly inquire about the potential effect or influence of the unit on their post-unit engineering aspirations, some students did indicate that the unit had promoted their interest in a future career in engineering. For example, Ivan responded,

> Recently? [Yes] Because I started thinking about being an engineer because after the arthritis project, I started to sew and make this and make the glove. I started to think about being an engineer because I did all of that.

For Ivan, it seemed the experience of acquiring a new skill and actively co-constructing his team's arthritis glove design helped him conceive of the possibility of him being an engineer. His words, "I did all of that," also indicated a sense of agency as being a primary reason for this greater interest in pursuing an engineering career.

Similarly, William, who, as noted in the previous discussion, had not really thought about becoming an engineer in the future, also signaled a greater interest in the possibility. In the dialogue sequence below, William explained why, after his participation in the PBSL unit, he could potentially be interested in a future engineering career:

> *William:* Yeah, possibly because I feel like it would be fun and um, yeah, it would be fun and probably like worth it.
>
> *Sneha:* Worth it in what way?
>
> *William:* Like, um like, as I said earlier, like it would be better for the world because like when I made the arthritis project I felt like better, because it like making—making something for somebody else, like, it felt, like, made me feel good. And you probably get paid decently.

Of particular note here is William's perception of an engineering career being "worth it." Describing the worth of an engineering career in relation to its potential contributions to society suggests that William viewed engineering as a potentially socially-purposeful profession and he associated positive feelings toward it. Furthermore, he indicated that this new perspective was influenced by what he experienced from participating in the PBSL unit. Finally, he also recognized that engineers have a higher earning potential, which aligned with his career priorities for financial security and stability, as discussed earlier.

It should be noted that while after the unit, most students were more inclined to consider engineering careers, two students, Ethan and Ezra, either did not desire to pursue an engineering career or still had a similar ambivalence (i.e., a "maybe") both before and after their participation in the unit. As discussed before, Ethan was committed to his aspirations in entrepreneurship, and thus, when asked when whether he would want to study engineering in the future, he explained, "Um no, because I don't personally—I don't find an interest in it." Ezra at first indicated that he would probably not want to become an engineer explaining, "Because all this stuff has already been like done, and I don't really have any more ideas;" however, later in his interview he did indicate that he was slightly interested in possibly studying engineering in the future. For both Ethan and Ezra, this was not necessarily a definitive dislike of engineering. That is, even in spite of their lack of interest in it, both students nevertheless commented on reasons or aspects of engineering that could be interesting to others and even to themselves elsewhere in their interviews. These reasons are further discussed in the ensuing paragraphs.

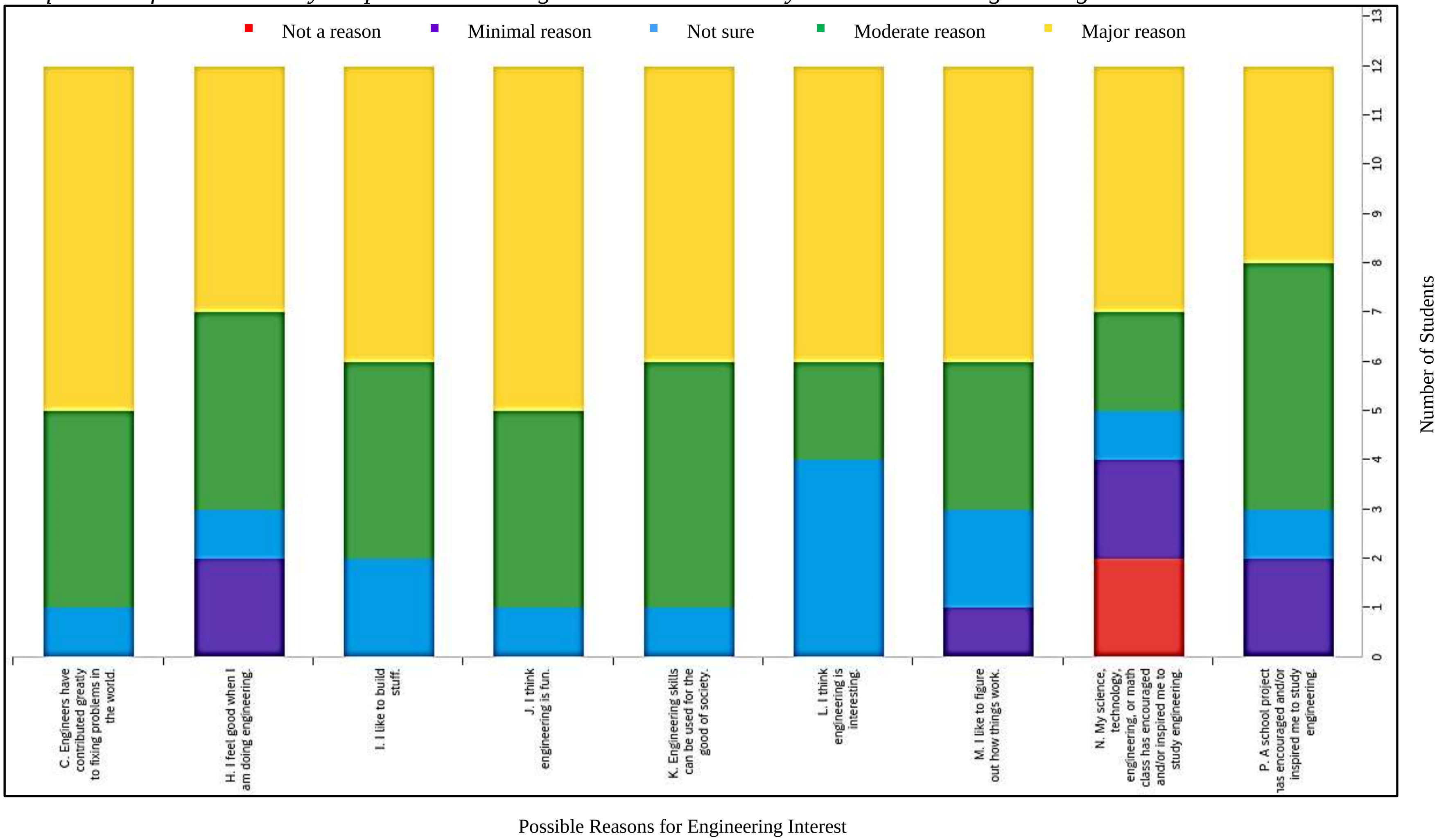
Reasons for Engineering Interest

The post-unit survey and interview protocol also explored the potential reasons why students might be interested in engineering. Figure 4.10 depicts the survey results of how strongly students agreed with certain reasons to pursue engineering.

The interview also further probed student thinking about their perceptions of and potential interests in engineering, based on what individual students indicated on their post-unit survey responses. The reasons students discussed as to why they were or might be interested in engineering generally fell into three affirmative categories; *engineering is fun/cool*, engineering provided opportunities for *curiosity, challenge, and learning*, and the *socially purposeful potential of engineering*.

Figure 4.10

Frequencies of Student Survey Responses Indicating Possible Reasons They Would Pursue Engineering in the Future



Engineering is Fun/Cool. At least six (46%) students explained that at least one reason why they would be interested in an engineering career was because they perceived it to be a "cool" or "fun" job. For example, Elijah explained that he wanted to be an engineer because "it can be cool to like engineer things, like make new products." Similarly, Ophelia noted, "I guess I just wanted to do it because it's the seemed cool that I could build stuff and invent stuff." Yohan also commented on how engineering could be "fun to learn." For all three of these students, engineering seemed to appeal to them because of its potential to create or make new things. Ezra also talked about engineering in similar terms while explaining why he might be interested in engineering: "'Cause it seems like I'd have a cool job and a lot of people could benefit from it." For Ezra, it appears that part of the reason why engineering appealed to him as being "cool" was because of the way it could help others.

Curiosity, Challenge, and Learning. Another appealing aspect of engineering that interested at least three (23%) students was the opportunities for curiosity, meaningful challenge, and "learn[ing] new stuff," as Ezra put it. Alan's reflections perhaps best exemplified how students saw engineering as an opportunity to be curious. In the following dialogue sequence, Alan explained this:

> *Alan*: Yes, because I like building and taking apart things, and I'm really curious about stuff and how it works with [inaudible] and engineering.
>
> *Sneha*: So is it important to you in your future job or career that you have opportunities to be curious?
>
> *Alan*: Um, yes because I could be curious about if this is going to work or not, like if this concept could work or this thing could work and we should test it, . . . if this thing should work or something like that.

In explaining how engineering could foster his curiosity, Alan inherently described how the engineering design process facilitates opportunities for curiosity by allowing one to conceive and test different ideas as well as manipulate things to better understand how they might work.

Despite her aspirations in a medical career, Ingrid also enjoyed engineering because she too perceived it as a context for curiosity and an enjoyable challenge. She explained:

> So at home, I remember, I remember trying to create a, it was with a cereal box. I tried to create a Post-it note dispenser, and it was really good, but you know, it was like more just for fun, but I like really thought about that, "Like what if I could actually create this? Like, what if I can actually do this?" And I really used—it's like collecting the toilet paper rolls, like the inside of it and creating something like that. It's like challenging for me, like in a nice, good way.

Here, Ingrid describes a self-directed engineering challenge she set out for herself. Not only did she seem to have embraced the sense of a meaningful challenge, but it was also motivated from her own curiosity and perhaps even a sense of agency.

Socially Purposeful Potential. For at least nine (69%) students, one reason for their interest in potentially pursuing engineering in the future lay in its socially purposeful potential. For students like Oscar and Ivy, who had preexisting interests in engineering, the possibility to help people was an added appeal of the profession. For example, Ivy commented, “Well, I mean, I have a lot fun doing it. And, like if I can, like engineer something—again, this ties into helping people—like if I can engineer something to help people that . . . I would very much enjoy that.” Here, Ivy expresses how, while she generally enjoys engineering, the potential to help people would further increase that enjoyment. Oscar also reflected on how his aspirations and interests in mechanical engineering could be of benefit to society:

> Probably because I'm helping with other—I'm helping people or building something that can help them, like if I were to become a mechanical engineer, I could like learn how to build cars and do something like that, and then I could help people get around … Cause for an engine—I mean, for a car to go, you have to have an engine in it.

In responding to a question about whether he sees engineering as something that can potentially help the community, Oscar not only affirmed this potential but volunteered a specific example, pertinent to his own aspirations in mechanical engineering, as to how engineers contribute to the world.

Students who had not necessarily previously considered or committed themselves to future engineering careers before the unit seemed to embrace engineering's socially purposeful potential as reasons for why they were more interested in it after the PBSL unit. This seemed to be especially true for Ivan and Ingrid. In reflecting on how he thought engineering could help the community, Ivan connected it to his own commitments to do so in the future, saying,

> Yes. I see engineering as a career that can help people in my community because when I grow up, people are going to be older and we grow older and when I become older, I'm gonna—I'm gonna have intention to help them 'cause I experienced all the things I need to do to help them.

Here, Ivan not only expressed an intention to help others through engineering, but he also alluded to helping the elderly, signaling an association of this intention with aspects of the PBSL unit, namely the age demographic of the service partners.

Similarly, Ingrid also expressed how she would consider being an engineer because of the potential to help people. She explained:

> I would consider being an engineer, as I said before, because it HELPS [emphasis articulated] people, and it really makes a difference in people's lives. And maybe it can even make a difference in the world. Like if you developed something small, like the arthritis device we made, it could really impact a small community, and it could get to a bigger community, and maybe even get to the world like the actual device developing, and being put in different places like shipping and stuff like that.

As her comments indicate, the service aspect of the PBSL unit seemed to resonate with Ingrid, helping her appreciate how engineering could potentially make a difference in the community. Indeed, Ingrid further imagined how these contributions could be scaled up beyond what students achieved by the end of the unit.

While many others among the student interviewees expressed similar sentiments and reflections, of particular import in these comments by Ivy, Oscar, Ivan, and Ingrid is the use of "I" statements. More specifically, all four of these students related the potential socially purposeful contributions of engineering to themselves as potential future engineers. Furthermore, their use of language like "I can," "I could," "I would," or "I will" also indicates that they perceived a sense of agency in their ability to positively contribute to society through engineering.

Summary of Chapter

The preceding pages provided a comprehensive account of student perspectives on how, if at all, participation in an engineering design PBSL unit contributed to middle school students' sense of purpose in life and perceptions of engineering. This account was heavily based on the salient themes from the student interviews from a sample of 13 students who participated in the project-based service-learning engineering design unit described in Chapter Three. The findings from the student interview data presented here were also triangulated with some of the relevant findings from the survey data and student artifacts from the unit.

Taken together, student perspectives could be considered within the three broader dimensions pertinent to this study: the project-based service-learning engineering design unit, purpose in life, and engineering. Student perspectives on the project-based service-learning generally centered around six major themes: *impact of/change after the unit*; *affect*; *meaningfulness*; *learning*; *team work/collaboration*; and, *agency*. The first of these, *impact of/change after the unit*, could be further parsed into two sub-themes regarding perceptions of *the impact of the unit* on student interests in and understanding of engineering as well as their sense of purpose in life. The *affect* theme also had two sub-themes: *an enjoyable experience* and *feeling good about/pride in oneself*. Students considered the PBSL unit as being *meaningful* primarily because of their perceived sense of it being either *personally important, personally relevant or significant*, or *authentic* in terms of both engineering and social purposefulness. Students also felt that they *learned* from the PBSL unit with their perceptions of their learning centering around four sub-themes: *learning in general, learning about issues in biomedical engineering, learning about engineering*, and, *learning engineering habits of mind and engineering skills*. *Teamwork and collaboration* was an important theme in student reflections on the PBSL unit with students describing both *positive team dynamics* and *negative team dynamics*. Finally, students also indicated a sense of *agency* while reflecting on their experiences with the PBSL engineering design unit.

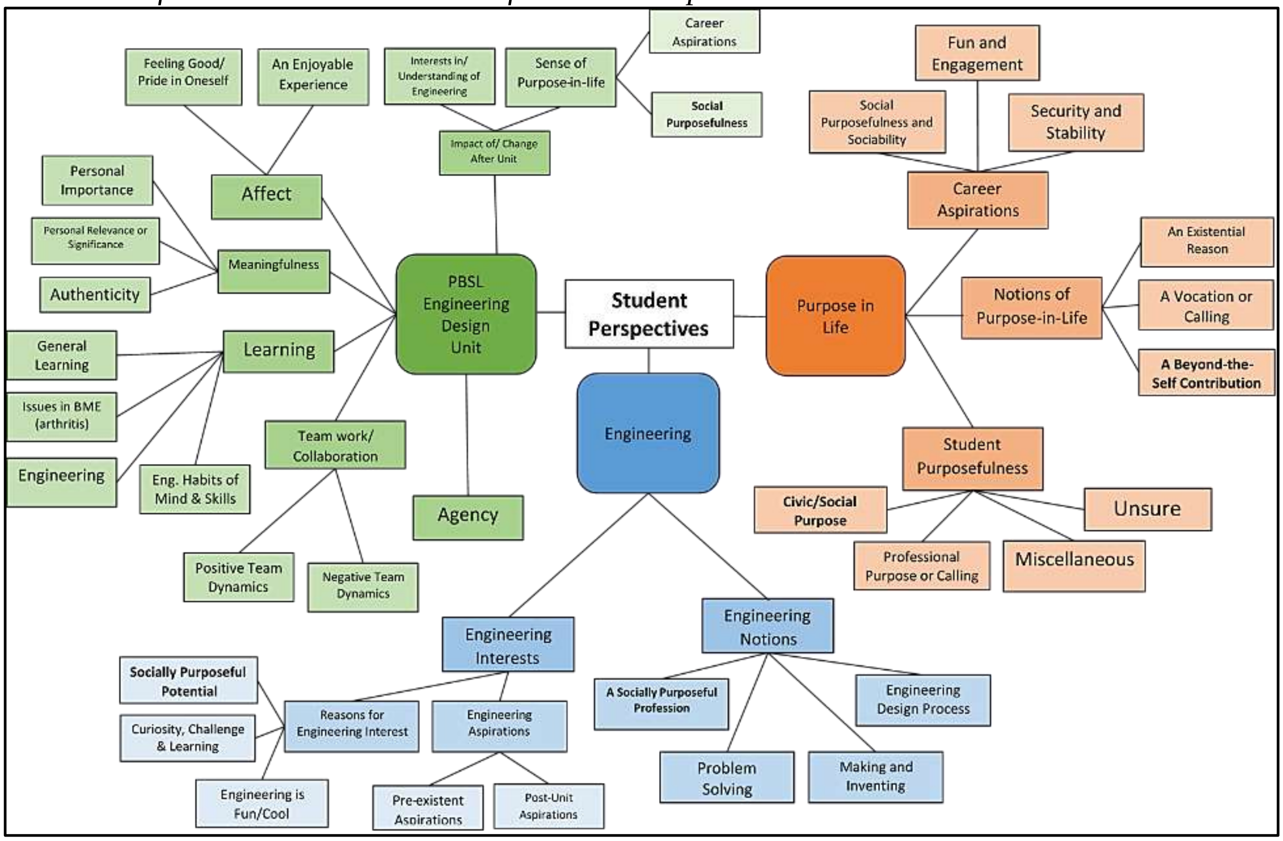
Student perspectives on purpose in life were categorized into three major themes: *notions of purpose-in-life, student purposefulness,* and *career aspirations.* The *notions of purpose-in-life* theme encompassed students' general conceptions of the construct, which seemed to fall under three sub-categories of purpose in life definitions: *an existential reason, a beyond-the-self contribution*, and *a vocation or calling*. The interview data also probed *students' purposefulness*, seeking to understand how students thought of their own purposes-in-life. Largely borrowing from Bronk (2014)'s typology of purposes, *student purposefulness* generally seemed to coalesce under these categories of purpose: *civic/social purpose, professional purpose or calling*, *miscellaneous purpose(s)*, and *unsure purpose(s)-in-life*. Finally, since students often associated their *career aspirations* with their purposes-in-life, there were three salient sub-themes of what students seemed to prioritize in their career aspirations: *social purposefulness and sociability, security and stability*, and *fun and engagement*.

Finally, student perspectives of engineering were discussed within two broader themes of their *engineering notions* and their *engineering interests*. Students' *engineering notions* encompassed their general definitions and conceptions of engineering. These notions seemed to cluster around four main sub-themes: *the engineering design process (EDP)*, *making and inventing*, *problem solving*, and engineering as *a socially purposeful endeavor and profession*. Students' *engineering interests* were parsed between their engineering aspirations, both those *preexisting* before their participation in the unit and those emergent *post unit*, as well the reasons for their *engineering interest*. Reasons for student interest in engineering included perceptions of engineering as: *a fun/cool job*; an opportunity for *curiosity, challenge, and learning*; and possessing *socially purposeful potential*.

It should be noted that two themes either seemed to underscore or recur in many of these discussions: a sense of agency and social purposefulness. Although a sense of agency was primarily discussed within the context of student perspectives on the PBSL unit, this theme also seemed to underscore many of their perspectives on purpose-in-life and engineering, as well. Similarly, social purposefulness was a recurrent theme in all three of the overarching dimensions (the PBSL unit, purpose in life, and engineering). Given the multitude of various themes discussed in this chapter, Figure 4.11 offers a schematic depicting the relationships of these various themes as presented in this chapter.

Figure 4.11

Schematic of Themes and Sub-themes of Student Perspectives



CHAPTER FIVE:
FINDINGS PART II: EDUCATOR PERSPECTIVES

This chapter presents the findings pertinent to the second research question regarding the educators' perspectives as to the important features and chief priorities that should guide the facilitation of an engineering project-based service-learning unit. As it relates to this question, the educators' perspectives generally fell under two overarching categories of perspectives: their *teaching priorities and strategies,* and their *impressions of the unit.* The "teaching priorities and strategies" category encompasses those views expressed by the teacher, Mrs. Daley, and the three expert engineers (Dr. Donne, Mr. Humberto, and Mr. Aldred), which signaled implicit or explicit curriculum or messaging priorities they endorsed for project-based service-learning (PBSL) engineering units, as well as any strategies they used or suggested to better centralize these priorities within the arthritis design challenge PBSL engineering unit. The second overarching category, the educators' "impressions of the unit," includes the thematic codes that described the educators' overall impressions of the arthritis design challenge PBSL engineering unit, particularly their perspectives on which aspects of the unit they perceived to be valuable or effective, or conversely, needed improvement or further development. It is worth noting that these overarching categories are not necessarily rigidly distinct from each other. For example, the insights the educators offered with respect to the strengths and areas for improvement in the unit's design arguably signaled the teaching priorities they held and strategies they espoused with respect to designing and implementing K–12 PBSL engineering design units.

Table 5.1 provides an overview of the primary themes and their corresponding codebook definitions used during the data analysis process of the educator interviews. Much like Chapter Four, the excerpts of the educator interviews presented here generally serve as representative statements for the shared views or reflections offered by the educators. In a few identified instances, these quotes may present a unique perspective offered by one of the educators. However, all participants' quotes serve to substantiate and clarify each theme.

Table 5.1

Codebook of Primary Themes for Educator Interview Data

Category of Educators	Primary Theme	Definition
Teaching Priorities and Strategies	Exposure to Engineering	Discussions or comments about exposing students, teachers, or the broader public to engineering. Generally included comments about valuing and fostering exposure to engineering. (Usually, the passage contained some variation of the word "exposure.")
	Messages About Engineering	Any explicit or implicit messages about engineering the educators wanted or hoped to convey. Included messages about engineering they seemed to emphasize, whether explicitly or implicitly.
	Hands-on/Physical Experience	Any references to engineering mindsets or habits of mind. Engineering habits of mind identified in the literature typically included: persistence, perseverance, collaboration, systems thinking, creativity, etc. Also included references to other "mindsets" or "mental frameworks"
	Encouraging Student Ideas	Discussions or comments about encouraging student ideas. Included anything from valuing student ideas to strategies educators used to encourage student ideas.
	Room for Mistakes and Failure	Comments about allowing room or opportunities for mistakes/failure, valuing mistakes/failure, or the role of mistakes/failure in the engineering design process.
	Teamwork	Any references to students working in groups or teams and their collaboration, or lack thereof. Included reflections about team dynamics, fostering teamwork and collaboration, etc.
	Involving Expert Engineers	Comments about engaging or soliciting the help of professional engineers during K–12 engineering lessons/units and involving them in the classroom.
Impressions of the Unit	Positive Aspects of the Unit	Aspects or points of the PBSL engineering unit that the educators thought were valuable or beneficial. (Overall positive impressions of the unit.)
	Areas for Improvement	Aspects or points of the PBSL engineering unit that the educators thought could be improved in the future or could have been better designed.

Teaching Priorities and Strategies

As noted above, the "teaching priorities and strategies" category represents the educators' perspectives on important features, goals, or teaching strategies they believe should be centralized in K–12 engineering experiences, particularly K–12 PBSL engineering experiences. These teaching priorities and strategies generally fell along seven primary emergent themes: *exposure; messages about engineering; hands-on/physical experience; encouraging student ideas; room for mistakes and failure; teamwork;* and *involving expert engineers.* The first two of these, "exposure," and "messages about engineering," appeared to be especially salient themes, and thus, they were further parsed into their related and respective sub-themes.

Exposure to Engineering

One recurrent priority, espoused by all four educators, was the importance of exposure, especially to engineering and engineering-related skills or experiences. The educators talked of this exposure as being crucial for both pre-college students and teachers, alike.

Student Exposure to Engineering

Both the teacher and the mentors discussed the importance of exposing students to engineering and engineering related skills. When asked why she was attracted to or interested in teaching engineering and the STEM disciplines using project-based service-learning, the teacher, Mrs. Daley, responded:

> What attracts me is I can see it being such a useful skill here these days and coming up. These kids are going to need to know at least the general idea of this kind of concept. I mean, even as an educator, I have to know. So, it's not really limited to engineering professions anymore, from what I can gather. So just giving them that exposure, giving them exposure to it, even with just my limited knowledge of it is what attracts me to it.

As her comments indicate, though Mrs. Daley did not necessarily consider herself to be especially knowledgeable about engineering and STEM skills, she perceived some value in exposing her students to engineering skills, noting that these skills were not only relevant to engineering careers but that they had wider relevance in society today. Though she did not necessarily elaborate on what this wider relevance might be, she nevertheless saw exposure to engineering and STEM skills and concepts as being necessary to sufficiently prepare her students for the 21st century.

All three of the expert engineers who served as mentors during the project also emphasized the need to create experiences that exposed students to engineering and engineering skills. Mr. Humberto, who had long been participating as an engineering mentor and spokesperson in a variety of STEM K–12 outreach efforts, explained that one of the key reasons he sought out and participated in these efforts was because he wanted to expose students to engineering, regardless of whether or not they actually chose to become one in the future. He commented:

> When I do my Engineering Day before—well, I think I said this before—that I'm not there to try to make all of you engineers. I know not all of you will be or [will] do other things. So I think the purpose of it, it might've made some students realize that maybe engineering might be something they would get into, it might have made other students realize that they don't want to have anything to do with this, and maybe some in between: maybe some that enjoy it, thought it was fun, but "might not be something I would want to do." So, it exposes everyone, though—it exposes everyone.

Though Mr. Humberto recognized that not all the students he talked to would pursue engineering professionally in the future and affirmed that neither should every student necessarily do so, he nevertheless desired to help expose students to engineering if for no other reason than to provide clarity in their career aspirations. Like Mr. Humberto, Mr. Aldred also expressed his desire to help expose young students to engineering and the STEM disciplines and teamwork especially, as discussed in the following dialogue sequence:

> *Mr. Aldred*: And obviously I wanted to help, I think it's a good cause and I want to support it.
>
> *Sneha*: Thank you. Okay. So, could you say more about what was the "good cause" aspect of this for you? Why did it seem like a good cause for you?

> *Mr. Aldred*: I think getting kids excited about STEM early on is important. And obviously there's a lot of initiatives that are trying to promote STEM education, and it was kind of this one didn't seem like there was any kind of discrimination or anything. Like there wasn't a gender discrimination. It was just like everybody—everybody's going to be working on this project and mixed group teams. So, I think that that kind of exposure to like working on a team, working on a team with people that are different from you, I think all of that is like really important. And I think a lot of the undergrads would be well off to have had some exposure to that before college.

Here, not only did Mr. Aldred allude to introducing young students to engineering and inspiring their enthusiasm for it as "a good cause," but his perception of this "good cause" was connected to his value for diversity in the field of engineering. Mr. Aldred believed that one of the best ways to foster appreciation for diversity and equity in engineering was to expose and engage students in working on diverse design teams early in their learning experiences.

Dr. Donne especially commented on how critical exposure was. During one segment of the interview, he reflected on how the lack of exposure to making and building something and the effort that entails can often lead to a lack of awareness and recognition of engineering innovations in everyday life. He reflected:

> I think [it's] the lack of exposure. You know, I think a lot of young people today take for granted the things that they interact with on a daily basis, unless you stop and think about it, then all the things that you interact with or that you find get joy out of in your life. Like, I don't know, they're just there. You know, we've come to have this commodity mindset, where, you know, there's not a lot of effort necessary to attain the things that you want. And, you don't really have to think about where it came from or who made it, or the years of work or innovations over the decades that made those things possible.

In this reflection, Dr. Donne commented on how the lack of exposure to building, making, and using tools combined with the promulgation of a utilitarian, commodity mindset has diminished critical experiences during which young students can gain a deeper understanding and appreciation for the complexity and intricacies behind the multitude of engineering innovations that outfit modern life.

Later in his interview, Dr. Donne explained why he took the initiative, during one of the class sessions he attended as a mentor, to bring in and discuss samples of 3D-printed orthopedic prosthetics and implants his company designed and manufactured. He explained this decision was especially driven by his desire to share his enthusiasm for his work, which was relevant to the students' assistive-device design challenge, and in particular to expose young learners to the vast evolution and applications of 3D printing:

> You know, right now, and especially over the last few years that kids are starting to get more exposure to 3D-printing and prototyping and, and those types of tools, the barrier to entry has gotten really, really low to have access to some of those things. But I think it's fun for people to see that, you know, these tools that even they have access to, professionals use them to use them too.

For Dr. Donne, in showing and exposing students to the real products of his work as an engineer, not only he was further exposing students to engineering and its innovations, but he also hoped to help students recognize the authentic nature of their design challenge in its resemblance to the types of problems his engineering firm seeks to address.

Teacher Exposure to Engineering

For the educators, exposure to engineering was not only important for pre-college students, but they also commented on its importance for pre-college teachers as well. Mrs. Daley, for example, expressed that one of her goals and motivations in collaborating with the researcher on the PBSL engineering unit was to gain exposure to engineering:

> *Sneha*: What about before the arthritis project, before we collaborated together, do you recall what were some of the goals maybe you had for the unit or the project?
>
> *Mrs. Daley*: Just to finish it. I was honestly, I was like, this is so so much higher level than I've ever even considered. I wondered the possibility of it getting completed at the very, very beginning. Just depending on what they chose to do. I think because I didn't have much exposure to that kind of process to begin with. I didn't have many expectations at all just to watch and learn, basically was my goal, which I did.

Here, Mrs. Daley acknowledged that because she previously lacked exposure to the engineering design process, she was eager to learn more about the engineering design process and how to teach it by collaborating on the design and enactment of this unit. Furthermore, Mrs. Daley's initial doubts at the beginning of the unit suggest that she perhaps questioned the extent to which students would be able to design viable solutions for an authentic. However, as noted in Chapter Three, students ultimately exceeded Mrs. Daley's expectations in what they designed and made.

Mr. Aldred independently affirmed the idea of teachers gaining exposure to engineering. In the following reflection, Mr. Aldred discusses how exposure can help teachers gain clarity about the distinctions between engineering and science:

> I think if you've never even, even if you're a teacher, if you've never had exposure to engineering, then you don't really know. You know, I think that maybe the challenge, if you've never had exposure to engineering is you think engineering is equal to science. That science, as you know, like, a pure science, is very demonstration-based, and engineering is not necessarily that. In science, you have a model that explains the concept, and that model works more or less every single time, but the engineering design process can be iterative, where you change your design and go back, and then you keep testing and validating. So if you've never been exposed to that, you might think that it's just a demonstration and if something doesn't work, then it's a failure. But I think no engineer would say if your first design doesn't work, you're a failure. I think that that's like a very important thing to teach the engineering design process that you might not know about without firsthand experience or talking to engineers. So that would probably be my advice.

Here, Mr. Aldred explains how "firsthand experience" with engineering or conversations with expert engineers might help teachers distinguish the epistemological and procedural orientations between engineering and science, in that the former is necessarily an iterative design process during which failure is often expected, whereas the latter is more oriented toward the development of explanatory models or theories. As Mr. Aldred suggested, this distinction is not often apparent unless teachers have exposure to engineering and have opportunities to witness or engage with the engineering design process. Mr. Humberto also echoed Mr. Aldred's points during his own interview, when he, too, independently endorsed the idea of teachers dialoguing with engineers to gain a deeper understanding of engineering. Thus, both the teacher and the mentors seemed to prioritize exposure to engineering at the pre-college level and for both students and teachers, alike.

Messages about Engineering

The educator interviews revealed that another priority for the educators was to convey certain messages about engineering. This was especially true for the professional engineering mentors, who espoused at least four key messages about engineering: *a problem-solving mindset*; *the engineering design process*; *designing within specifications and constraints*, and its *purposeful potential*.

A Problem-Solving Mindset

At least two of the three mentors, Dr. Donne and Mr. Aldred, emphasized the importance of seeing engineering as an approach to problem-solving. Dr. Donne, in particular, repeatedly commented on how it was important for students to understand that engineering, at its essence, provides a mental framework for problem-solving. When asked what he hoped students would learn about engineering or what he wanted to communicate about engineering, Dr. Donne talked of the problem-solving mindset:

> *Sneha*: As an engineer, what did you want to communicate, demonstrate, or otherwise hope students would learn about engineering, or your field?
>
> *Dr. Donne*: Yeah, I would say I would hope that in any experience like this, the students could come away with—or my hope would be that they can come away with that mental framework to approaching a problem. Or, they would see that there is a structured way of thinking about difficult problems or difficult challenges that is manageable and you can break it down and set your focus on specific parts of a problem and set your requirements around solving those specific parts of your problem, and then come out there and actually produce something that is a working solution. Because I think without that mental framework or kind of understanding of the design process, anything you try to go do is going to seem overly daunting. It’s gonna seem unattainable, but if you can get your mindset right, and there that mental framework, right. And you can see the ways or the areas of a problem where you can effect change or be successful.

Here, Dr. Donne distilled the essence of engineering as being a problem-solving heuristic that is encompassed within the engineering design process. Furthermore, Dr. Donne's reference to engineering as a "mental framework" or a "mindset" of problem-solving suggests that he viewed engineering as an epistemic stance, and one that young learners could develop and apply to solving problems in almost any context.

Separately, Mr. Aldred also echoed Dr. Donne's message about engineering as a problem-solving mindset. Mr. Aldred also described engineering as a mindset of "solving hard problems":

> I also think that it's important for them to understand what engineering is and that part of that mindset is solving hard problems. . . . But I think having an understanding of what it is before you go into it, that's not motivated by your career or doing something that sounds cool. I think realizing that what engineering is, at least mechanical engineering, is working with your hands and solving hard problems. It's not always that, but in general, it's this encountering difficult situations and figuring out how to design your way around them or through them. I think that having a healthy understanding of that is good.

Like Dr. Donne then, Mr. Aldred also saw that communicating to students that engineering, at its essence, is a problem-solving mindset was a priority lesson for pre-college engineering education. In a similar vein, Mr. Aldred also commented on the importance of embracing struggle and encouraging perseverance as a part of the problem-solving process. To this point, he offered this reflection:

> And I think engineering attracts the kind of people that really like solving difficult problems that have a solution. . . . And I think that realizing that struggle and appreciating it—because I think that . . . there's more or less two types of people you can encounter with that kind of struggle and say, this is too hard. I give up, which I think you saw some of the students just kind of, you know, let the rest of their team handle most of it. But then you really saw a few students, in particular, I think that kind of got it, that it kind of clicked with them. So, I think that encountering that struggle and not looking at it as "Well, this is just hard. I don't want to do it," but actually engaging with something that's hard. I think that that's important. Even engaging with something that was hard just for the sake of it being hard is an important part of engineering design.

Here, Mr. Aldred describes how, in many ways, the nature of engineering is centered around engaging with and persisting through difficult problems. As such, he espouses a mindset that embraces challenging problems, struggle, and even moments of failure, a point that will be further expounded in an ensuing discussion. Furthermore, Mr. Aldred sees this willingness to engage with difficult problems as being essential to the engineering design process, which in itself was another priority shared among the educators.

Engineering Design Process

All four educators also emphasized the importance of the engineering design process as a fundamental aspect of engineering. Mr. Aldred, for example, spoke about the engineering design process being a core component of any engineering unit when asked what advice he would give to K–12 teachers who would like to teach engineering. He said:

> So, I think if you're going to try to teach a unit on engineering, you have to do it the way you did it with the arthritis group of, we're going to teach the engineering design process. And in the end, you were going to build a thing because that's how engineering works. It's taking a problem, figuring out how to solve it, and then solving. And I think that each piece in that puzzle is kind of critically important.

Mr. Aldred's response here discusses how the engineering design process is at the crux of problem-solving in engineering. As such, Mr. Aldred saw teaching the engineering design process as being "critically important" to engineering curricula. Dr. Donne and Mr. Humberto echoed Mr. Aldred's points here throughout their respective interviews, often commenting on how a key takeaway for students should be understanding the engineering design process as a problem-solving framework. Indeed, at one point during his time serving as an engineering mentor during the unit, Mr. Humberto volunteered to give a mini-presentation on the engineering design process for students.

Mrs. Daley also seemed to recognize and prioritize the engineering design process as a central idea to incorporate within her curriculum. When discussing her goals for the following academic year and her potential new teaching assignment as the Makerspace & Technology

Coordinator, Mrs. Daley commented on how she planned to focus on teaching the engineering design process:

> And I would try to focus on the engineering design process just to kind of distinguish between the Makerspace elective and the STEM elective... . So I definitely have plans to incorporate it, no matter what capacity in that school next year, whether it's classroom teacher or Makerspace technology coordinator I do plan to go through the engineering design process again and probably bug you a lot about it.

Here, Mrs. Daley's comments not only reflected a commitment and a goal to centralize the engineering design process within her curriculum the following academic year, but they suggest that she saw the engineering design process as a distinguishing feature between making (and engineering) and other STEM disciplines.

Specifications and Constraints

Another prevalent message at least three of the four educators highlighted was the necessity of identifying and designing within specifications and constraints. Mr. Humberto particularly reiterated this point during his interview. For instance, when asked what he hoped to communicate to students about engineering, Mr. Humberto replied:

> Well, I don't know if I communicated it or not. I do when I have my engineering days, but, one thing to communicate is that an engineer in the real world, when you are working on a problem or trying to solve something, there are always going to be constraints, constraints in terms of time or in terms of expense. And the important thing is going to be to work within those constraints. And in other words, you never have a completely free hand at cost or time; if you take too much time, whatever you're working on will be obsolete anyway, And function, of course. You have to have at least this level of function [gestures with hand to show a level of minimum function], if you have more function well, that's great, but there's a minimum level of function that you have to have again within all those constraints of time and expense. And I think they got some of those constraints now, for example, expense to buy supplies, there was a limit on that. As far as function, well it was a loose constraint, I guess.

For Mr. Humberto, it was important to authentically mimic the reality of engineering practice, that is, designing within identified specifications and constraints. He also explained why this message and skill was important, noting that unbounded design processes may result in obsolete, irrelevant, or non-functional solutions. With regard to the assistive-device PBSL design challenge, Mr. Humberto acknowledged that Mrs. Daley and I did well to include budgetary constraints, though, as further expounded upon later in this chapter, we ought to have done better to hold students to the identified functional specifications and constraints.

Dr. Donne also agreed with Mr. Humberto's sentiments, himself commenting on the importance of encouraging and helping students stay within the bounds of identified design specifications and constraints. During a longer reflection about engaging engineering mentors throughout the engineering design process, Dr. Donne discussed this point, noting, "When you've identified your needs and you identified what your requirements for your device had been, you know, those were decisions that you had made as a group. [Then you're] trying to stay true to those decisions." Thus, Dr. Donne also thought it important for students to learn to adhere to identified design specifications and that they ought to be held accountable for designing within these specifications and constraints throughout the engineering design process.

Although, as noted previously, Mrs. Daley did not have much familiarity with teaching engineering, she, too, remarked on the value of having students design within constraints and specifications. Mrs. Daley commented on how she came to appreciate and recognize the value of incorporating design constraints, such as a budget, whether arbitrary or real:

> Because now that I'm thinking about it, too, one of the questions you asked earlier, something that was successful or having the budget, giving them even when it was arbitrary and like, what was it when we charged them for the board games where we said like, even though there was no real money exchanged, but just having like the penalty for working over the weekend and stuff. That was mind-blowing for me. Like even though it was completely arbitrary and, you know, having that self-check for them, I guess you kind of leveled the playing ground because they all had a limit to their materials. And I don't know. Anyway, I told another teacher about it. I think it might have been the technology teacher and his substitute when she took over his makerspace class. I can't remember, but a budget or price or whatever for it and penalties like that. That was really what was different and exciting for me to implement. Then of course, then it came to *real* budget.

Of particular note here is Mrs. Daley's perspective that the budgetary constraints not only helped keep students accountable, but she also perceived that they helped "level the playing [field]," as it were, in that all students and design teams were held to the same concrete limitations and access to resources. Furthermore, within the context of the entire arc of the PBSL unit, Mrs. Daley also saw the value of having even simulated or arbitrarily-defined constraints during an early mini-design challenge because it scaffolded students into working within the constraints of a real budget during the assistive-device design challenge. For Mrs. Daley, this was such a poignant idea that she even shared this strategy with a colleague in the school, discussing with him its benefits.

Purposeful Potential

When asked about their own sense of purpose in life or engineering's potential for purposefulness, the educators, particularly all three expert engineers, saw engineering as possessing much potential to cultivate social purposefulness. Dr. Donne, for example, explained how his personal experience of watching a family member benefit from innovations in assistive devices inspired his interest in biomedical engineering, particularly because he saw it as a way to positively impact people's lives:

> And you know, for me, especially in high school, I had teachers telling me that, "Oh, you're good at physics and, math and science and building things, you should be an engineer" and you look at yourself and go, "Well, okay. But what is that like? What does that mean? What does being an engineer mean?" . . . But, as I stepped back and looked at it, I realized that I have a younger sister who is a dwarf—she's a little person, and I was able to step back and realize that I had been a witness to engineers making a difference in her life for my whole childhood. . . . And I kind of had, I guess, an aha moment that, you know, I had witnessed all the ways in which engineers have the capacity to better someone's existence.

As Dr. Donne reflects here, though his high school teachers had encouraged him into engineering because of his aptitude for mathematics and physics, it was only upon realizing the potential for positive social impact that can be achieved through biomedical engineering that was he convinced to pursue an engineering career. Thus, for Dr. Donne "the capacity . . . to better someone's existence," is an important facet of engineering and one that continues to motivate his practice.

Mr. Humberto similarly commented on the socially purposeful potential of engineering. When asked whether he saw engineering as potentially intersecting with or contributing to one's sense of purpose in life, Mr. Humberto responded:

> In terms of engineering, engineering is one of their purposes is to improve things, make things better, make things easier. Progress. And I guess that would be a reason, or why I, or someone would get into engineering for the improvement of things. They can be building better things for mankind to make life easier... . And then, well another part of that, so you do want to do some good, leave some kind of mark that's making things better, or you help someone or some group, help someone or some group improve their life or make life easier, whether it's with projects or ideas or et cetera.

For Mr. Humberto, engineering, at its essence, is generally oriented toward improving life and society. It is by virtue of this inherent drive toward societal progress and helping improve the lives of others through which an engineer might find a sense of purpose in life.

Mr. Aldred independently concurred with Dr. Donne and Mr. Humberto, similarly commenting on how the vast innovations borne of engineering have improved society and people's lives:

> And especially, I mean, I think engineering comes from wanting to make society better. We need roads, so we need people to design the roads, and we need to cross rivers. So we need to build bridges. So, it comes from these roots of making people's lives easier. So, I think that it absolutely is a moral decision because with that power also comes the ability to make people's lives worse. So, I think that considering the aspect is certainly important, but I think that it's vastly under-considered.

As Mr. Aldred points out here, engineering is not only potentially purposeful, but also a moral endeavor. While elaborating on this point elsewhere in his interview, Mr. Aldred also discussed the nuance and the importance of considering the moral implications of engineering pursuits. He noted that while many engineering pursuits can certainly have positive moral connotations, there are also certainly others that may have arguably immoral motivations and negative social impacts.

As such, as noted in the preceding excerpt, Mr. Aldred highlighted the importance of having conversations that explore the moral and ethical implications of engineering, particularly its potentially positive and negative impacts on society.

Hands-on/Physical Experience

The educators also keenly emphasized the importance of young students having opportunities to engage in the hands-on or tangible experiences of making or building. Dr. Donne and Mr. Aldred, in particular, repeatedly stressed the physicality of many engineering disciplines and the invaluable learning students could experience from using and working with tools. In one of his several reflections regarding students using tools, Dr. Donne reflected on how the lack of exposure to such experiences has deprived students of all ages, sixth-graders and undergraduates alike, of foundational skills that are fundamental to engineering experiences, processes, and thinking. He remarked:

> Whether it's determining what the right tool is to execute a task or picking out the right bolt or the right spring for your component, all of those things that on their face seem very simple, you know, have a lot of underlying assumptions or engineering decisions that need to be made in order for you to be successful. And I don't think we do an excellent job in our education today of exposing young people to those things, you know. So often, that is left to the domain of home and the experiences that you might have working with your mom or dad, in the garden or in the garage, or we're working on a car and, you know. It's one of the areas where I feel like I have a little bit of a soapbox, you know? The movement away from the trades within our education system is, has been very detrimental to our ability to build and execute on a technical level, I guess, as a society.

In this reflection, Dr. Donne both explained the importance for young learners to know how to properly use tools and lamented the loss of vocational arts and trade programs in the pre-college landscape. He saw the lack of opportunities for tool-use and vocational programs as tantamount to depriving students of essential technical learning experiences that are also germane to engineering processes.

Mr. Aldred similarly discussed the innate physicality of engineering, especially mechanical engineering, and the importance of learning how to use tools in order to meaningfully engage in engineering. When asked what advice he would give K–12 teachers who wanted to teach engineering, Mr. Aldred offered this reflection in response:

> I think mechanical engineering is kind of the quintessential, it's kind of like the gateway into engineering because it's very physical. So, I think that engineering, at least mechanical engineering, is necessarily physical. I think that it's very important to have a phase that you are building something. And I think it's very important for the students to be able to build it and learn that when you use a hacksaw, it's really hard to cut a straight line, and your pipe is going to come off at a weird angle, and you're going to have to live with that for now. But you're learning that that's how the hacksaw works. Stuff like that I think is *really* valuable. And, I think it's impossible to separate that from engineering when you're teaching. . . . I think that when you're teaching engineering, you need to teach just building and like taking an interest in the way things work. And that has to come from the hands of the student. Like, you have to put the tools in the hands of the student and let them figure them out kind of thing. So I'd say that's probably the most important thing that K–12 educators should know, is that like when you do a science demonstration, it's usually a demonstration, . . . but engineering is not really explaining concepts; it's explaining a process in a way of thinking that you can really only get at by physically doing something.

Here, Mr. Aldred vehemently professes the ways in which student learning about engineering is amplified and strengthened by giving them opportunities to work with their hands and use tools. Indeed, Mr. Aldred believed that such experiences should not simply be a mere enhancement to engineering education but rather an integral part of it because, as he notes in the preceding quote, engineering is "necessarily physical."

Mrs. Daley also acknowledged the importance for students to have space to tinker. While discussing some of the challenges of the unit and ways she would like to improve upon the PBSL unit in the future, Mrs. Daley discussed the importance of having a physical space to do so:

> I think another challenge was the physical space we worked in and I'm hoping that since next time we do this, the Makerspace lab will be opened that it will be easier to actually work just because we'll have more space, we'll have the right tools available. They'll be able to perhaps see and manipulate the stuff before they—I'm sorry, we had that goal with the proxy prototype, but I think having the Makerspace lab would help a lot... . so they

> have the space to get dirty and to mess up and to, you know, use a drill and not have to worry about the class next door.

Though Mrs. Daley primarily commented on the necessity of having a proper physical space that would allow students to engage in tool use and the messiness of making, she also alluded to the need for students to have the emotional or mental space for them to do so as well. Thus, as in Mrs. Daley's comments, the educators very much prioritized and valued students having ample opportunity to physically manipulate their designs in order for them to grow in appreciation for engineering and the design process.

Encouraging Student Ideas

All four educators also sought to encourage students' ideas throughout the engineering design process. They discussed the strategies and the challenges they encountered during their attempts to encourage student ideas. Dr. Donne, for example, explained how one of the most enjoyable aspects of mentoring students was being able to celebrate student successes and ideas. He noted:

> You know, I'd say what I enjoyed the most about it is the opportunities that you have throughout the process to like celebrate small successes within their work, or really highlight for them good or innovative ideas that they had and be able to make sure that they understand why what they just came up with is actually really cool. 'Cause they're just trucking along, right? They're there, they're in it. They're getting their hands dirty, they're working. And I think they need that outside perspective to point out that like, "Hey, Oh, the way you put that, that spring or that rubber band there, you know, is really, is really neat and a really elegant solution"—for these reasons and celebrating those things.

Dr. Donne, then, encouraged students' ideas by employing the strategy of expressly recognizing the value and merit of students' ideas and solutions. In essence, he helped them metacognitively reflect on why a certain idea or solution may be a worthy one to pursue.

All three of the professional engineering mentors also commented on the challenge of negotiating providing guidance to students without overinfluencing students' ideas and "stifling their creativity," as Mr. Aldred had put it. Mr. Humberto's reflections were representative of this shared sentiment between the mentors:

> When they came up with an idea, that was why, I mean, I'm never positive that it's not gonna work, right? I'm never positive, but you're pretty sure things aren't going to work. So therefore, I give them my opinion and tell them what the problems may be. But I think it's still valuable for them to, they insist on trying it, and I'm not going to push too hard either to not try it. You tell them once you know, "I don't think this is going to work," but you don't want to insist if they want to go on, "Well, that's fine," and that's fine to let them go on. And who knows, maybe they'll prove me wrong? It's happened. It's happened. So you can't push too hard. You can't push your opinion too hard. . . . You think about, "Well, it's going to cost them time and et cetera, they don't have to come back and redo it." But, I guess you have to tell yourself, well that there's, I guess, value in that if they want to insist on trying and go ahead and try it. And you know, maybe they'll learn from that too. I don't know.

As Mr. Humberto expressed, though he felt conflicted between guiding students away from likely unsuccessful engineering decisions and allowing them to pursue an idea, he also recognized the value in allowing students to explore their ideas. As he noted, it was important that he not insist on his own opinions too much, and instead only gently suggest or provide perspective, ultimately allowing students the opportunity to make the final design decisions.

Mrs. Daley also discussed the tension of negotiating student ideas with providing them important scaffolds or structures to guide the success and design of the unit. In considering different approaches to various aspects of the design of the unit, Mrs. Daley reflected on the benefits and disadvantages of pre-selecting or pre-identifying potential service partners for a PBSL engineering unit as opposed to having students identify service partners within the unit. She mused:

> Maybe if I were to do it again, reaching out to certain people to come to the classroom instead of leaving it so broad and open, like, okay, these are the places you can reach out to. You don't have to pick one of these, which I know kind of defeats the purpose as well. . . . Because I don't know if we would've gotten to the arthritis device had we done that.

As Mrs. Daley thought aloud here, it is evident that while she recognized the logistical and time value of potentially pre-selecting a service partner in future PBSL engineering units, on the other hand, she also recognized that it might limit student choice in the design of the unit. This is reflected in her last sentence, where she acknowledges that had we pre-identified a service partner or community issue to anchor the unit, the arthritis assistive design challenge might not have been the central design problem of the unit, since the students, themselves, had identified that problem within their community. Thus, in this sense, it was a student-driven idea that formed the basis of the design challenge for this PBSL unit.

Room for Mistakes and Failure

As a corollary to encouraging student ideas, the educators, especially the mentors, also emphasized the importance of allowing room, or creating a "safe place," as Dr. Donne termed it, for students to make mistakes and fail. Though espoused by all three professional engineering mentors, this notion of allowing room for mistakes and failure in the engineering design process was especially reflected throughout Mr. Humberto and Mr. Aldred's interviews. In a similar vein to his comments above regarding allowing students to explore their ideas, Mr. Humberto discussed letting students fail:

> *Sneha:* What was most challenging or difficult in mentoring students during this project?
>
> *Mr. Humberto*: Oh, probably pulling back, they get an idea, right? They want to go with it, and you might critique it and, but they still want to go with it. They still want to try something. I mean, I can see they're just not going to work. And, but once I critique it, that's all you can do if they still insist on doing it, I guess you have to let them that, that was kind of hard to just let them go ahead and fail because I think in most cases where I thought it wasn't going to work, it actually did not work. But, they insisted they wanted to try it, so "Okay. Okay, have at it!"

Although Mr. Humberto discussed this concept of room for failure as being one of the more challenging aspects of mentoring in this capacity, he nevertheless recognized the importance of "pulling back" and letting students try their ideas out and possibly fail. For Mr. Humberto then, allowing students to fail was necessary in the effort to encourage student ideas.

Mr. Aldred endorsed a similar view. Indeed, Mr. Aldred discussed how mistakes and failure were germane to the engineering design process and should thus be valued within early engineering education experiences. He commented:

> Just reinforcing that [failure], that's part of the process. It's not even like, "Oh, well, we're reflecting and thinking about what will be better." It's actually part of the engineering design process. And it's a critical component, and what I think makes it different from a science project. So even though their projects kind of flow like a science project, because you do a problem, you build a thing and you demonstrate it, engineering is all about now, what will we do different, whereas science projects kind of end and that's fine. That's okay. It's just a different thing. I think, highlighting that difference, I think that that would help make the students whose projects didn't work, feel a little bit better about it—like, if they realize that it's very uncommon to get your first prototype working very well.

For Mr. Aldred, the importance of allowing room for failure is multifold. First, not only did he believe it to merely be typical of the engineering design process, but he indeed characterized it as being "a critical component." Moreover, he discussed the role of failure as being the impetus for iteration and improving. He also saw failure's integral role within the engineering design process as a distinguishing feature between engineering and science, the latter of which he seemed to perceive as being more terminal in its process rather than iterative. Finally, Mr. Aldred noted that valuing and normalizing failure and mistakes can be pivotal to encouraging young students during early engineering design experiences, where failure might be common, so that they are not discouraged or dissuaded from engineering due to undesirable experiences with failure.

Teamwork

The educators also had much to say about teamwork and collaboration. Mr. Humberto and Mr. Aldred, in particular, stressed the importance of teamwork, while Mrs. Daley discussed the strategies she thought helped facilitate teamwork. Mr. Humberto explicitly noted how communicating the importance of teamwork is a priority for him when teaching engineering design. He commented, "The other hard thing is getting the idea of teamwork across to them:

teamwork. When I do my engineering days and they're going to work on the hands-on project, it's always in groups of four, three or four. And one of the things I constantly emphasize is teamwork." Elsewhere in his interview, he explained why it was crucial to emphasize this aspect of engineering:

> Because that's how you are going to end up with the best end product. In other words, if you entertain all ideas, you may have a great idea, but there's going to be somebody else who's going to offer improvements or have something to offer that maybe better than what you have there. In other words, to optimize whatever it is you're working on: to get everybody's idea and really sort through them and figure out which is the best approach. And, then, and even after that, after you get whatever the best is that everyone has to offer, you may prototype something. And then there may be more ideas on how to improve it also. But that's where teamwork comes in, trying to get everyone's best ideas out there. Everyone's ideas, good or bad, you know, sometimes the person that has an idea, thinks it's not good, but you never know for sure until they get it out there and see what other people think. So anyways, that's how you end up with the best overall product or overall project.

As Mr. Humberto points out here, teamwork and the unencumbered exchange of ideas is fundamental to optimizing innovations. He thus prioritized fostering positive team dynamics and encouraging students to share their ideas to cultivate their sense of the value of collaboration.

Mr. Aldred shared similar views about the fundamental necessity of collaboration and teamwork in engineering. He agreed with Mr. Humberto that teamwork and collaboration often produce more optimal results than working alone. Moreover, Mr. Aldred also commented how the benefits of teamwork is especially enhanced by diversity in team composition:

> So what's interesting about—you probably know this—but there's a lot of study on adding diversity to project teams. And, diversity across the board, can get you better, more creative results, but it takes longer, . . . but it actually has proven results... . But the group dynamics are super important, like trying to recognize people's strengths and separate by tasks. Because I think that's what's different is, or at least, difficult is taking your project and having an idea of what to do and then being able to divide the labor amongst your team that makes the most sense and caters to people's interests and abilities, like "You can work on this component, I'll work on this component, and then we can come back up and join them together." I think that that's a valuable skill.

As Mr. Aldred suggested here, encouraging diversity in and allowing time for teamwork and collaboration during the engineering design process can spur creativity. Additionally, Mr. Aldred pointed out how collaborative skills, such as the division of labor, particularly as it might align to individual team members' own skills and interests, as being keen and valuable engineering design skills.

Much like Mr. Aldred, Mrs. Daley espoused using the division-of-labor strategy to facilitate better teamwork and collaboration among students. In discussing some of the teaching strategies she found to be effective during the unit, Mrs. Daley commented on how encouraging students to divide the labor amongst themselves by assigning team roles helped mediate students' team dynamics. She noted:

> I think assigning roles for each of them, which was not something that I've done before—although I wanted to—but finally having a concrete name, I guess, for those roles and descriptions for those roles made assisting them easier because I was able to say, "Okay, whose role is that supposed to be?" and it helped squash a lot of the quarrels that they would have because they're doing this, well, you know—that whole thing. So, I think that part of the planning... . I'm thinking about the research, kind of breaking it down with who's doing which part of the research, helped the planning go smoother. So yeah, assigning specific roles for each of the students within the group.

Here, Mrs. Daley described how assigning specific roles within the teams helped mitigate some of the team tension. She found this to be particularly effective during the research and planning phases of the unit. Thus, as Mrs. Daley's, Mr. Humberto's, and Mr. Aldred's reflections indicate, the educators roundly endorsed the importance of teamwork and cultivating effective collaboration skills, as they ultimately facilitate more productive and innovative engineering design processes.

Involving Expert engineers

All four educators unanimously endorsed the value of involving expert engineers. As will be discussed in greater detail later in this chapter, this was also a point which the educators identified as an area of improvement within the unit. Even so, the fact that educators saw this strategy as having room for refinement is nevertheless indicative that the educators saw that involving expert engineers as mentors for students was a priority strategy that could strengthen the design of PBSL engineering units, or indeed, K–12 engineering units more broadly.

Mrs. Daley, in particular, commented on the tremendous role the professional engineering mentors played in helping students work through the engineering design process. To this point, she remarked:

> They [the mentors] were a huge role. I would not have been confident about them actually physically building those devices without even like [one of the students' parents] who's not a professional without AT LEAST somebody like that who can help with [that]… . I think that they were valuable in helping the students think through—because I know like with—oh, now the names are escaping me. So, [Mr. Aldred], especially, [Dr. Donne] too, did a good job helping first try to figure out what the goal was before they just started doing something, like, "What are you trying to achieve by doing this?" And I know [Mr. Aldred] really was able to help them, I don't know, work backwards in, in essence? Because I would've just been like, "Okay, here you go, have fun!" But they were—I mean they really took the time to teach them how to, you know, "Okay, if you use this tool, it's going to do this. It's not going to do—" you know, and helping them find the right—you know, shop class, I guess basically incorporating just the basic elements of how to sew or what the different tools even do."

For Mrs. Daley, the professional engineering mentors were not only critical in helping her feel more confident in guiding students through the building phase, but she perceived them as being very valuable guides in helping students think through and reflect on their process and providing them important instruction on tool-use.

Mr. Aldred also saw the involvement of expert engineers as being a valuable asset to early engineering experiences. When asked for his thoughts on how schools or teachers might facilitate or recruit expert engineers to serve as mentors in future pre-college PBSL engineering units, Mr. Aldred reflected:

> So in recruiting, if you're going to highlight one particular type of engineering and I'm biased, but I think mechanical engineering is the most quintessential of the disciplines. I think just making sure that all of your engineers that you choose have at least a tangential background that can go back to that core discipline. I think it was really cool that we had

> practicing engineers, a guy with a PhD in biomedical engineering. So that's like very mechanical, but also very relevant to the arthritis project.

Of note here is Mr. Aldred's appraisal of having practicing engineers, especially engineers with relevant expertise, serve as mentors during the project. Moreover, he especially endorsed the strategy of involving engineers with disciplinary backgrounds that align with the type of engineering problem that may anchor an engineering design challenge or unit.

Speaking more broadly about ways teachers can support students in learning about engineering, Mr. Humberto also advocated the strategy of engaging expert engineers to visit pre-college classrooms. When asked what advice he would give teachers who wanted to teach engineering, Mr. Humberto replied:

> Well, one advice is, if it's at all possible, to get an engineer to visit your classroom, for one thing. There's plenty of engineers out there, right? Everyone knows it's an engineer or more so instead of the teacher talking about something that they have not practiced or studied, actually get someone that has trained in that and is out there practicing to come in and talk to their classroom. That'd be probably my number one advice to have a visitor come in and talk about that. Because I know when we did it in high school, the teachers were, I mean, they were so appreciative. After all they're not engineers, and they haven't really practiced it. And then after that, maybe the instructor to get some advice from whoever visits your classroom.

Here, Mr. Humberto explains how involving engineers in the classroom can be beneficial not only for students, but also for teachers who may lack a solid foundation in engineering principles. He argues that engineers are able to offer important perspectives and advice on what engineering practice is like. He also notes that in his past service of doing K–12 engineering education outreach work, he often found that teachers were immensely appreciative of having engineers visit their classroom to offer these authentic expert perspectives.

Impressions of the Unit

The educators' impressions of the unit included their perspectives and assessments of those attributes of the PBSL engineering unit that that they believed to be especially strong or in need of improvement. As such, there were two salient primary themes within this category, both deductively derived: *positive aspects of the unit* and *areas for improvement*. Each primary theme had multiple sub-themes, all of which are further discussed below.

Positive Aspects of the Unit

When asked about their general impressions of the unit, what they most enjoyed about the unit, or what, if anything, the unit was successful in teaching about engineering, the educators identified several aspects or features of the unit that they spoke of in overall positive terms. Among these various aspects, the most common themes centered around six ideas: *successful introduction to engineering*, *engineering design process and habits-of-mind*, *authenticity*, *motivation and purposefulness*, *student ideas,* and *student accomplishment*.

Successful Introduction to Engineering

One positive aspect consistently identified by the educators was that the PBSL engineering design unit did well to introduce young learners to engineering and other skill sets. For example, when asked how, if at all, the unit succeeded in teaching students about engineering, Dr. Donne responded, "I think it was very successful at fostering exposure and helping change, I guess, kids' mindsets about the problems that they encounter or problems that they see within their communities." Similarly, when she was asked a similar question regarding the potential benefits of using project-based service-learning to teach engineering, Mrs. Daley had this to say:

> Gosh, the benefits are numerous. There were so many life skills that they learned through the process communicating with outside agencies, communicating with the principal you know, writing the letters, doing the budget, and then just exposure to the discipline that they may or may not get. I think even if the project itself, like if there are concepts would have failed, I think they still had valuable lessons within it, like working as a team, designing for others, the budget.

Thus, according to both Dr. Donne and Mrs. Daley, one of the chief benefits of the PBSL engineering design challenge was that not it only fostered student exposure to engineering, but it also exposed them to and encouraged their development of important skills and thought-processes like: having a problem-solving mindset; budget-planning; communicating and engaging with community members; and, collaborating in teams. In this sense, then, the educators saw the value of PBSL engineering units as being a prime context through which young learners can gain exposure to engineering and engineering skills.

Engineering Design Process and Habits of Mind

The educators, especially the engineering mentors, also saw the unit as being successful in teaching students the engineering design process and, by corollary, engineering habits of mind. For example, Mr. Aldred commented on how the unit did especially well to emphasize and engage students in the “process” aspect of engineering design:

> I think that it taught engineering well in that the design process is a process. It’s not, you take a problem and then you just go ahead and you just like start sprinting in a solution; it’s calculated and it’s slow. And that can be frustrating I think, especially to kids in that age that they just want to—I mean, for anybody really—but they haven’t, they haven’t had anything like this where they’re telling you like, “No, actually you need to slow down and think about your design.” So, I think that that’s important to teach it as a process and that we need to come up with a bunch of ideas and then down-select what the better of those ideas are before we start building, and we need to have an idea of what it’s going to look like. So, I think that that was, that was taught well.

Here, Mr. Aldred explained how the unit encouraged students to take a step back and carefully consider their design decisions and plan their process. He also alluded to the experience of frustration that students may have experienced from such a “calculated and slow” approach, but the necessity of encouraging students to persist in this approach, nevertheless. In these ways, then, Mr. Aldred’s comments reflect how, in his view, the unit was successful at demonstrating the engineering design process and cultivating the habits of mind that are necessary to thoughtfully engage and persevere through this process.

Mr. Humberto also agreed that the unit facilitated students' learning of the engineering design process and fostered their adoption of engineering habits of mind. The following dialogue sequence presents Mr. Humberto's perspectives on these points:

> *Sneha*: In terms of engineering skills or processes or ways of thinking, how did the project help or not help or could have done better?
>
> *Mr. Humberto*: No, I think it helped, because I know the students came up with ideas that I'm sure they thought were gonna work right. Because they would come up with ideas and actually put them into practice, and they got a chance to see that maybe they didn't work or they didn't work so good. And then, when that happened, they'd go back and either try something entirely different or try, maybe improvements, changes on what they already had. So I could see that they were going through a process of: innovate, design, build, test, and then, start over again—the cycle to try to get either to make it better or try to get it just to work, period. And, I didn't really see anybody giving up or anything, or at least the groups as a whole. I mean, they were determined, they were determined to get something working and to actually get something built.

In describing what he observed, Mr. Humberto explained how he saw students engaging in an iterative process of design. In so doing, he found that altogether, students exhibited a sense of determination and persistence in their goal to create a functional assistive device.

Authenticity

The educators, unanimously, described the unit or features of the unit as being authentic. They often pointed to how the unit promoted the development of important real-world skills, like budget-planning, as Mrs. Daley pointed out, and the authentic nature of the problem at the center of the design challenge. This latter point was especially salient among the engineers' reflections on the unit, who all used the word "real" to describe the assistive-device engineering design challenge that anchored the unit.

When asked what he most enjoyed about the project, Mr. Humberto referred to the authentic nature of the project:

> Well probably once again, the practical application of the project, they're actually learning and thinking about something that's a natural product that's actually useful in real life as opposed to straight book learning, I guess, where you actually maybe take some of what

> you've learned or that you also to get a chance to exercise your creativity and which students like that age, they're still very imaginative, right—creative. And so, watching them use that into a real product, into something that will have an actual application and actually helps somebody actually make things easier for somebody. I really enjoyed that.

Here, Mr. Humberto describes the nature of the unit using language that heavily signals his perception of its authenticity. First, he acknowledges the unit as having a "practical application" aspect. He then refers to authenticity when he talks about the students' ultimate device designs: a "real product," potentially "useful in real life," "actually helping" someone, or something "that will have an actual application." Furthermore, he points out how the design challenge provided a context where students could use both their creativity and imagination within a real-world context and translate their ideas into reality.

Dr. Donne also alluded to the project's authenticity while describing his overall impressions of the unit. He particularly commented on the authentic framing of the design challenge:

> I thought it was really fun. It's nice to see, you know, any school projects I think that come rooted in identifying a societal need or trying to frame things in terms of real-life experience. Certainly in my years of education, those are the types of projects that always, I think, stick with you. And you remember the most that have like some level of practicality, . . . and I don't think young people or kids are often forced to think through the reasons behind a problem so often they're just presented with, you know, this is a problem and here are some of the solutions that are out there. And so, I liked the fact that the project really forced them to think about a problem and then drill down into the root causes of that problem in a detailed way that I think is not part of your everyday experience when you encounter or are presented with a problem.

Like Mr. Humberto, Dr. Donne appreciated the project's "real-life" framing. In this passage, he also highlighted how the unit was anchored around an actual "societal need," further noting that this authentic and practical framing of learning experiences tends to have lasting impressions on learners. Hearkening back to Mr. Aldred's and Mr. Humberto's comments above regarding the unit's effectiveness in teaching the engineering design process and to his own previously-quoted reflections about engineering as a problem-solving mindset, Dr. Donne' discussion on how the project compelled students to thoughtfully think through the anchor problem also suggests that he saw the unit as engaging students in an authentic problem-solving and engineering design process. That is, not only was the unit authentic in its framing of the anchor problem, but it was also relatively authentic in engaging students in the problem-solving and design processes germane to engineering.

Mr. Aldred also expressed similar views about the benefits of designing a unit around a real need. Elaborating on some points he had made about the moral and purposeful aspects of engineering, Mr. Aldred discussed how the authenticity of the unit inherently incorporated a sense of morality and purposefulness:

> I think that it's the perfect kind of project. One, because the students can see that it's meeting a need that's real. So convincing students that trying to learn a new manufacturing technique is actually really cool and valuable to society is often—they're not going to connect with that. But seeing that like, Oh, my grandfather has complained about arthritis and to think that I could make a device that might help them like that's very tangible. So, I think that there's that component that students are very, it's very tangible for them to see. But also, I mean, designing components that help people is critically important. And I think that there's so much innovation that comes out of trying to help people that are underrepresented or have some kind of disability. It's actually a really prosperous area in research right now of empathic learning of how do we empathize with the non-standard user and how does that change our design? . . . So, I think that in the context of that moral framework, this arthritis project, it fits perfectly in addition to being able to be extremely tangible for the kids to see.

Here, not only does Mr. Aldred refer to the central design challenge as addressing "a need that's real," he points out that anchoring the unit around a problem that students can recognize and relate to within their own contexts, such as a relative's struggles with arthritis, concretizes the value and purposefulness of engineering. Mr. Aldred then goes on to discuss how the specific design challenge of creating assistive devices very much resonates with a burgeoning field of engineering research and innovation in empathetic engineering design. In this sense too, then, Mr. Aldred's comments reflect the authenticity of this unit as both, being realistic in its framing as well as in line with new frontiers of engineering innovation. Of course, underscoring his reflection here is Mr. Aldred's reflection on how the unit's central design challenge highlighted the purposeful aspects of engineering, another aspect of the unit which the educators also acknowledged as being a positive one.

Motivation and Purposefulness

As some of the mentors' reflections around the authenticity of the project implied, the educators also saw the unit as being overall motivating and engaging and contributing to a sense of social purposefulness for students. All three mentors as well as Mrs. Daley discussed this view within their interviews. For example, Mr. Aldred commented, "I think I was like, firstly, liking it—it's very encouraging to see like the student engagement. And there's obviously some people are going to be more into it than others, but it was it was really cool to be able to see some of the students really latch on to, you know, being committed to their little project." Thus, Mr. Aldred felt the unit was overall engaging and observed a sense of student ownership of the project. Furthermore, as briefly discussed in the preceding paragraphs, Mr. Aldred also affirmed that the unit certainly helped foster a sense of social purposefulness, or at least contributed to helping students see the socially purposeful aspects of engineering. He explained how this was evident in the central design challenge of empathically designing for elderly relatives who struggled with mobility challenges as a result of their arthritis condition.

Mr. Humberto also alluded to how the unit was motivating for students, noting, "I'm sure the students also probably felt pride in actually making something that is not a toy or something that has no real purpose, but actually trying to build something that should help somebody, . . yeah, that helpfulness." Mr. Humberto pointed out that students likely felt a sense of pride, particularly because of the socially purposeful nature of the design challenge in that it was oriented toward helping others.

This theme was extensively apparent throughout Mrs. Daley's interview. In her responses to various questions regarding her assessment of and perspectives on the unit, Mrs. Daley often commented on how the unit motivated students and contributed to the students' sense of purpose in life.

While explaining how her participation in the unit fostered her own self-efficacy in teaching engineering, Mrs. Daley reflected:

> I think just in how I design a lesson especially talking about hands-on learning opportunities, whether it's like the table-top board game or like the puff mobile thing that we did, you know, even just those smaller, quick experiments or hands-on activities the way we set them up, giving them the—some different information that I guess in the past, I just kind of assumed they knew. Incorporating the reflection piece afterward, that was a big game-changer for me. Having them design for other people, like the tabletop game that we did—watching them get excited because they're doing it for more of a purpose than to just be doing it.

In describing how she learned more about incorporating hands-on and reflection opportunities to design more engaging STEM and engineering experiences for students, Mrs. Daley also noted how students seemed excited about the assistive-device design challenge of the unit precisely because it had "more of a purpose" to it as opposed to a more decontextualized engineering design challenge.

Elsewhere in her interview, Mrs. Daley also commented on how the unit was intrinsically motivating for students. She noted, "Beforehand the only engineering thing really, I've ever done—it was not quite the motivation was winning a challenge, but with no actual like reward just bragging rights, basically. And I think seeing them create a functional item was motivation in and of itself." Mrs. Daley contrasted the motivational strategies between her past lessons on engineering design to the PBSL engineering unit; she highlighted how the objective and need to create a functional product through the assistive-design challenge was intrinsically motivating to students, as opposed to the more competition-centered strategies she's used in the past to motivate students during engineering design challenges.

Mrs. Daley also affirmed that the PBSL unit potentially contributed to some students' sense of purpose in life. When asked how, if at all, the PBSL unit impacted students' sense of purpose in life, she responded:

> I think for some it *did*. I think for some, it did greatly give them a sense of purpose or a sense of pride, a sense of accomplishment and exposure to things that they can see themselves doing later in life or reaffirming those decisions that they've come to at such a young age already; contributing to that sense of, "Yes, I do want to be an engineer and, and this was an integral part in confirming that for me, even though I'm only 12," you know? Not something that I would have thought of before we started, probably definitely something that I'm only thinking about because you asked. ... . But, I can see how for a couple of them, especially listening to their interviews with you, 'I was like, wow, okay. That was really—[Mrs. Daley trails off]" You know? And, I think for those that want nothing to do with engineering, having gone through this process will still help them in some way, for sure.

Although Mrs. Daley acknowledged that while she did not necessarily consider how the PBSL unit potentially impacted students' sense of purpose in life until I asked her, she noted that she certainly saw that for some students, the PBSL engineering design unit was impactful in helping them affirm or broaden their interests in engineering and clarify why they might want to pursue a career in engineering. In particular, she noted how the sense of pride and accomplishment students derived from creating the assistive devices could have contributed to confirming future aspirations in engineering or to developing their sense of purpose. Moreover, since Mrs. Daley served as the adult chaperone for some students' post-unit interviews, she also had a chance to listen to student responses on the interview. She noted here that in so doing, she also saw how the unit potentially contributed to students' sense of purpose in life, whether or not they had an interest or future aspirations in engineering.

Student Ideas

Another positive aspect of the unit the educators discussed was that it provided opportunities for students to explore and act on their own ideas. Mrs. Daley, for example, highlighted how one successful aspect of the unit included the concept-generation phase, when students proposed initial ideas of designs for an arthritis assistive device:

> Successful parts of the unit—let me think . . . I think their initial design concepts when they each had to come up with their own concept I feel like they all did a really good job kind of drafting that initial idea when we narrowed down the arthritis part that they really thoughtfully considered what they should incorporate before joining those concepts together for a group one.

Mrs. Daley discussed how students not only did well to generate ideas for an assistive device concept, but that they did so thoughtfully and with deliberation. Furthermore, she alluded to how they used a similarly thoughtful approach to synthesize and refine their collective ideas to settle on a single design for their respective teams.

Mr. Aldred also noted how he enjoyed watching students attempt an idea despite what uncertainty they may have had. He noted:

> I think what I most enjoyed was obviously you didn't get this with every group, but the few groups that were able to make something that actually worked, and you could tell they really surprised themselves. I think that that was really cool, that moment of surprising yourself because something works and you weren't sure if it was going to come together. I think that's a feeling I've had a lot throughout the various projects that I've worked on.

Mr. Aldred described how it was gratifying for him to observe students take risks, pursue their ideas, and sometimes surprise themselves when those ideas ultimately ended up being successful. Thus, as Mrs. Daley's and Mr. Aldred's comments indicate, the unit was effective in allowing opportunities for students to generate, deliberate, and pursue their own ideas.

Student Accomplishment

For both Mrs. Daley and Mr. Aldred, another positive aspect that resonated with them was what students were able to ultimately accomplish by the end of the PBSL unit and design challenge. Mrs. Daley commented on the overall success of the students' design process, noting that most groups were able to have at least some level of functionality for their final prototypes. She remarked, "'I'd say it was pretty successful? I mean, four out of five groups had working functional prototypes for the most part." Similarly, Mr. Aldred noted how he was impressed with the level of productivity students were able to achieve:

> I was also—another impression—I was impressed with how much they were able to get done with relatively little tools and, you know, stuff that's just in a classroom that normally you would need to go to a machine shop for or something. Or I think comparing it to what you see kind of in the undergraduate level, like student projects, everybody just 3D prints everything now. So, it's kind of become sort of a crutch that you can lean on because you can just 3D print whatever you want. So, you don't have to think about how you're going to actually cut a piece of metal or anything. So, it was cool to see that really hands-on engagement.

Mr. Aldred commented on how much students were able to accomplish in their design process with relatively basic tools and without access to sophisticated machinery and tools like 3D printers. Indeed, he saw their lack of access to these advanced machinery as a benefit precisely because it prevented them from being reliant on these tools and instead required them engage in using and manipulating tools and objects to achieve similar results. Additionally, Mr. Aldred's reflections here about the unit promoting students' hands-on engagement hearken back to some of his previously-cited comments about the importance of prioritizing hands-on making experiences for students in engineering education. Thus, for both Mr. Aldred and Mrs. Daley, an important positive aspect of the unit included the relative success or functionality students were able to achieve in their designs, particularly as a result of their own hands-on engagement.

Areas for Improvement

While the educators identified several positive aspects of the PBSL engineering unit's design and enactment, they also spoke to areas of improvement and refinement that could enhance future enactments of pre-college PBSL engineering curricula. More specifically, the educators identified at least four primary areas of improvement: *facilitating teamwork*; *adhering to design specifications and constraints; involving expert engineers throughout the process;* and *timing.* As discussed later, the last of these, *timing*, had two sub-themes pointing to two main ways in which the educators discussed how this aspect of the unit could be improved.

Facilitating Teamwork

One area for improvement consistently identified by at least three of the educators was strategies to better facilitate teamwork and collaboration among students. In general, the educators perceived an imbalance in the distribution of responsibility among team members. Mrs. Daley, for example, noted how much of the subpar collaboration she observed among groups often manifested in an unbalanced distribution of work among team-members:

> This might be a question you have coming up, but I'm going to go ahead and incorporate it here. I think the only thing holding me back from saying completely successful would just be the collaboration between the students. You know, some of those teams, one or two students basically doing all of the work on their own and either for whatever reason that student not wanting to participate or just because of the personalities, the stronger-willed students. I think that is the one thing I will really be thinking about when I do it again, is how to group them.

Here, while Mrs. Daley identified various factors that could affect team dynamics in unideal ways, she also reflected that there are potentially better strategies, such as different grouping schemes, to facilitate teamwork and collaboration.

Mr. Humberto independently agreed with Mrs. Daley's assessment that students' team dynamics were often unbalanced. He observed:

> One improvement is teamwork was okay, but not great at all. Not great, each team seemed to have a student in there that it was more of a leader than others. I may have covered this before already, but normally the leader, if a leader emerges, one of the most important things is to draw out the other participants, draw out their ideas and make sure that they get heard.

As Mr. Humberto noted here, although it may be fairly expected that a group leader emerges, one important way of teaching collaboration skills is to emphasize to students that a crucial responsibility of a team leader is to seek out and value their team members' input. They should actively seek to solicit their group's ideas and encourage the entire team to give these ideas their due consideration and fair evaluation. For Mr. Humberto, then, this key lesson on teamwork was under-emphasized during the assistive-device PBSL engineering unit and ought to be centralized in future iterations of similar projects.

Mr. Aldred also spoke to how teamwork could have been better facilitated during the unit. In so doing, he, too, offered some suggestions for strategies that might help improve this aspect of future iterations of pre-college PBSL engineering design experiences:

> Maybe just some self-reflection. I think that trying to engage the students that seem a little checked out, because I think that the kids that really latch on tend to dominate the conversation, and that's true of basically any group project, but I think that I don't think I did a good job of reinforcing good team roles. Like I think that I would tend to enable the kids that were latching on because you get excited too. It's infectious. So, then I think that the people that suffer are the ones that weren't as engaged, almost like they get to the point where they just missed the boat. They're so far behind that they're not gonna really plug in to contribute because it's kind of too far gone. And I think that there's not that many students that did that. I'd say there's the ones that really latched on. The ones that really didn't are probably about equal. And then there's like this big group in the middle that are like engaged and interested, but not like, freaking out because they're so excited. I feel like you saw some of that. So I think I would like to try to engage the other students a little bit more, and I don't know how to do that.

Mr. Aldred discussed his perception of the distribution of student engagement or participation within their teams, noting that in his estimation, student participation in their teams was overall not too dire, though not necessarily excellent, either. Like Mrs. Daley and Mr. Humberto, he also attributed differing student personalities as being one potential cause for these imbalances. However, interestingly, he also took ownership of the responsibility to facilitate better team dynamics. Though toward the end of this response, he expressed some uncertainty about effective strategies that might have better engaged those students who seemed more disengaged or timid, he also first suggested a strategy of promoting self-reflection. Though it is unclear whether he intended this strategy of self-reflection on team roles for students or the teachers and mentors, it is perhaps likely that either, and indeed both, stakeholders would benefit from such reflection and that it would potentially foster more productive and balanced team dynamics.

Adhering to Constraints and Specifications

As noted earlier, one of the points the educators emphasized about engineering was the importance of designing within the stipulated constraints and specifications. One of the primary ways this point emerged as a priority for some of the educators, especially for Dr. Donne and Mr. Humberto, was in their discussions of how the unit could be improved. That is, for Dr. Donne and Mr. Humberto, one key area for improvement was to help students better adhere to the constraints and specifications identified for the design challenge.

Dr. Donne explained how he observed this gap within the unit. In this longer excerpt of some of Dr. Donne's previously-cited comments on this point, he reflected on when he observed students diverging from the design constraints and specifications:

> Because it's really easy once you get into like the prototyping and building phase of things to start to creep away from some of those—I mean, some of those really, what they are is they're truly decisions that you had already made. Right? So when you've identified your needs and you identified what your requirements for your device had been, those were decisions that you had made as a group. And so trying to be—trying to stay true to those decisions through what is the really fun, really interactive prototyping portion of it I think maybe got lost a little bit, but I think it was because there wasn't enough touch. It would have been nice if there could have been, you know, an adult kind of working with each group throughout the entirety of the process to be able to keep them on course and keep them true to the decisions that they had and the requirements that they had set forth for themselves. There was a lot of pivoting that happened.

Dr. Donne explained how the prototyping or building phase of the design process was the point at which students struggled to stay within the design decisions they had identified for themselves earlier. However, this was the key point during which students needed to adhere to these specifications and constraints. As such, Dr. Donne thus believed that involving professional engineering mentors earlier in students' design process might have helped scaffold students toward developing this important engineering design skill. This point is further examined in the subsequent discussion.

In a similar vein, Mr. Humberto also discussed how the unit would have been improved by more defined time constraints and by keeping students more accountable to this constraint. To this point, he explained:

> And then I guess they have sort of a time constraint, but it was very loose... . Anyway I don't know if she [Mrs. Daley] does that or somebody who does that again it'd be useful to actually have a fixed number of what class sessions or to work on this. And then at the end, you're out of time, show me what you have.

Here Mr. Humberto acknowledged that though there was an attempt to incorporate a time constraint, this time constraint ended up being rather flexible. He proposed defining a fixed number of class sessions for students to prototype and construct their designs and holding them accountable to this time constraint, irrespective of how much progress they achieve with creating their designs.

Involving Engineers Throughout the Process

As noted previously, all four educators unanimously agreed that it would have been more beneficial to have involved the professional engineering mentors throughout more of the students' engineering design process. While they all had slightly differing viewpoints as to when it would have been optimal to have involved the engineers, all four educators agreed that their involvement needed to have begun earlier in the students' engineering design process. Since some of the educators' perspectives on this point were previously discussed in this chapter, the present discussion will only focus on the viewpoints offered by Mrs. Daley and Mr. Aldred as they relate to this theme.

In discussing aspects of the unit she would improve and build upon, Mrs. Daley noted that she would perhaps try to involve engineers much earlier in students' design process. She suggested that perhaps the optimal time to involve the engineers was during either the concept-generation or planning phase:

> I don't know how much it would take away from the student learning because I know that that was the whole goal, but maybe finding a [mentor] partner to help them even with just the design concept and the ordering of materials. I think bring them [the mentors] in sooner, just to have that adult mentor through a little bit more of the process than just the actual construction while emphasizing to the mentor that they're not there to tell them what to do or what to order, but to help them cross all their T's and dot all their I's.

As Mrs. Daley posited here, having the professional engineer's input during these early stages of the design process might have helped students attend to important finer details and also help keep them true to the identified specifications and constraints. However, Mrs. Daley is quick to also emphasize that it would be important to remind the professional engineering mentors that they should avoid simply directing or controlling students' design process or their projects, but rather should serve as guides who help scaffold students throughout their design process.

Mr. Aldred also agreed with the idea of involving engineers earlier in the design process, though he diverged from Mrs. Daley on the point of involving them during the students' concept-generation phase. Indeed, Mr. Aldred expressly noted that the expert engineers ought not to be involved during that phase:

> I think maybe one thing that could have been done better, I think bringing in the engineers was really interesting. I think that there's a lot of different expertise and backgrounds. It may have been helpful to bring them in a little earlier, like during the, the concept-selection stage really. So, one phase earlier. So, I think that it's okay for them to, I think it's important actually for them to come up with all of their designs without an engineer's input, because that's where you can really harness some of that creativity that they have by not ever having done something like this before. But I think once it comes to actually spec'ing out components and stuff that might've been helpful to have some engineers just in the loop a little bit. I think that by the time I was working with the students who kind of seemed like a lot of their designs were fixed and now we need to figure out how to build it, whereas if I had had some input maybe a little bit before then result could have been a little better. And I realize that that's difficult because you don't want to put a lot of people out for longer.

Thus Mr. Aldred certainly espoused the potential benefits of engaging the engineering mentors earlier. He believed the variety of expertise they might offer would have been a valuable asset from some of the early stages of the design process. Though he did not believe the expert engineers should be involved during the concept-generation phase, lest they exert too much influence on students' imagination and creativity, he did agree with Mrs. Daley that the engineers ought to have been involved shortly earlier than they had been, particularly to help students better identify which among their ideas would most likely succeed and plan out the necessary materials they would need to achieve their designs. It is important to note here that both Mrs. Daley and Mr. Aldred stressed that while the engineers' early input would have been keenly valuable, encouraging student ideas should always remain a top and central priority. That is, the engineers' input must always be oriented toward helping students transform their own ideas into reality.

Timing

The educators also discussed how the overall time-management throughout the unit could have been improved. The educators discussed two ways in which the timing of the unit could have been more optimal: in terms of the *unit's pacing* and allowing *time for failure and iteration.*

Unit Pacing. Two of the educators, Mrs. Daley and Mr. Humberto, commented on the pacing of the unit. While Mrs. Daley did not necessarily see the unit's overall pacing as being problematic, she did comment on the importance of considering time constraints while planning and enacting PBSL engineering units. She reflected:

> I think as far as—did you say pitfalls? I think time constraint, that would probably be the biggest you know, for a regular science lesson an hour is almost too long, but on the days we did this stuff, an hour was not nearly long enough. So, I think just the timing of it—not that it was a bad thing. Just something to consider.

Here, Mrs. Daley ruminated on the challenge of negotiating time constraints and trying to anticipate what quantity of time would be sufficient for students to meaningfully engage in the various tasks of the unit. She notes that often an hour did not seem nearly adequate. Thus, as Mrs. Daley's comments indicate, it is important to consider and plan adequate time for students to engage in the design process.

In contrast, during his interview, Mr. Humberto repeatedly commented on how the unit's pacing was perhaps too long. He also discussed how the pacing of the unit might have been improved had it had more consistent and continuous pacing, saying, "And then I know there was an interruption in the project, but it would be better nicer to have it continuous, no interruptions start to finish maybe except maybe some space—time between coming up with ideas and then starting construction." Here, Mr. Humberto suggests how a more continuous flow of pacing would have been more optimal for students' design process. However, he does allow that perhaps some time between the concept-generation or planning phase and the construction phase would also be necessary. It should be noted, that while a more continuous pacing would have been far more ideal, this was not possible to achieve during this unit, not for lack of desire but rather because of time constraints in the researcher's schedule.

Time for Failure and Iteration. Two of the mentors, Mr. Humberto and Mr. Aldred, also considered how the timing of the unit needed to better allocate time for failure and iteration. Mr. Humberto, for instance, pointed out that "it has to be long enough so that they have a chance to fail once or twice."

Independently elaborating on this point, Mr. Aldred also suggested that one area for improvement in the unit was to allow more opportunities for students to iterate and improve upon their designs:

> And now that I'm thinking about it, I think that one of the most important things in teaching engineering is concentrating on the iterative process. So maybe we could have done a better job at the end. And I, we tried to talk about this, but I think that engineering and that process is all about continual improvement and that's where the iterating comes in. So obviously we only had time to do one iteration. They couldn't really double back and improve designs, which that's fine in most projects like in class and stuff, you're not able to do that,

> but a big component is about recognizing your successes and your failures and then what you would change. So, maybe it doesn't necessarily end when you finished your first prototype. Like it's all about thinking about, okay, well, if we were to go do this again, if we were to have this budget or this whatever, and I think that we tried to teach that, but maybe making that a requirement as part of their presentation; I don't know what their guidelines for their presentations were.

Here, Mr. Aldred described how iteration is a crucial part of the engineering design process and that to the extent possible, it is important to allow students time and opportunities to do so. However, recognizing that often there are external factors that may necessarily impose time constraints or limits in the classroom, Mr. Aldred noted that it is at least important that students are encouraged and have opportunities to reflect on how they might iterate upon their designs. Although Mr. Aldred suggested that this reflection component be incorporated into students' final design presentations, he was unaware that it was indeed incorporated as one of the guidelines for students' final design presentations. Nevertheless, his comments here suggest that perhaps the unit could have provided more time and opportunities for students to iterate and reflect on improvements.

Summary of Chapter

The objective of this chapter was to elucidate the salient themes that characterized the participating teacher and three professional engineering mentors' (i.e. the educators') perspectives with regard to the instructional features and priorities they saw as being important to facilitating pre-college PBSL engineering units, especially as they might foster youth purposefulness and interest in engineering. The findings presented in this chapter coalesced under two overarching categories: the educators' perspectives on *teaching priorities and strategies* and their *impressions of the unit.*

Within the first of these categories, "teaching priorities and strategies," there were seven emergent primary themes: *exposure to engineering; messages about engineering; hands-*

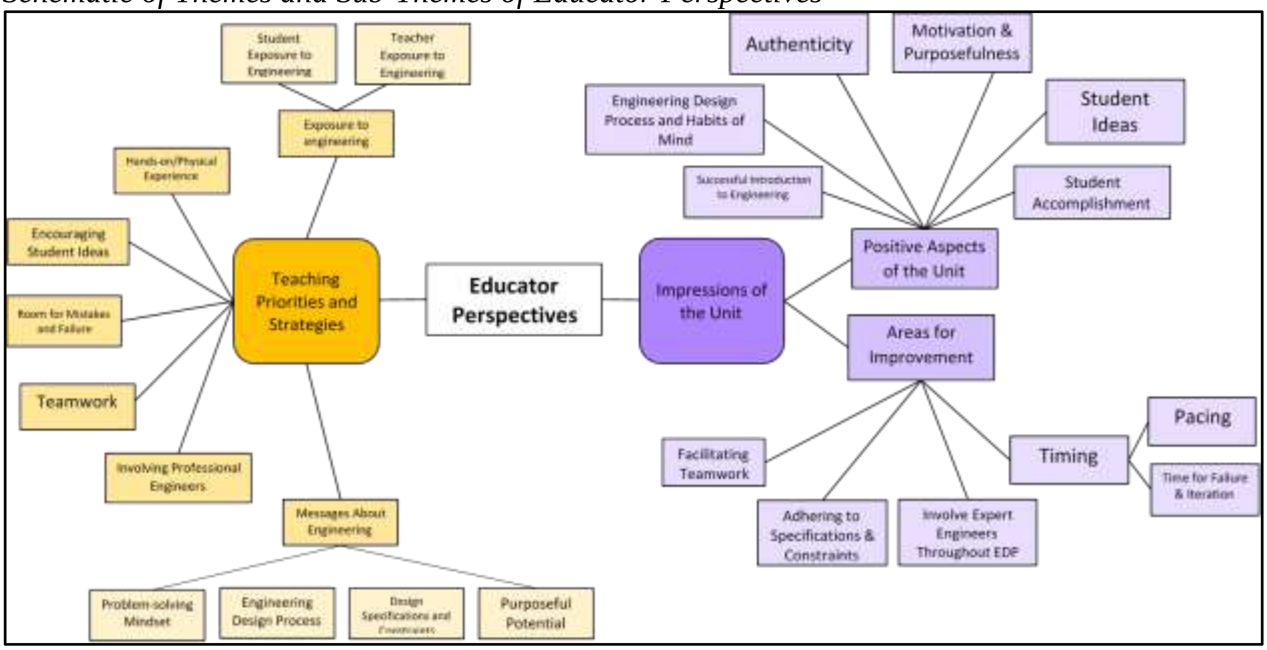
on/physical experience; encouraging student ideas; room for mistakes and failure; teamwork; and *involving expert engineers.* The educators discussed "exposure to engineering" in two main ways: *student exposure* and *teacher exposure*. Similarly, the educators, especially the mentors, had four main priority "messages about engineering" they seemed to want to convey: *problem-solving mindset*; *the engineering design process*; *designing within specifications and constraints,* and, its *purposeful potential.* These sub-themes either often discussed a message about the nature of engineering the educators hoped to convey or a skillset and/or mindset they hoped students would develop with respect to engaging in engineering experiences.

The educators' "impressions of the unit" could be further classified into two primary themes: *the positive aspects of the unit* and the *areas for improvement* within the unit. They identified at least six key features of the unit that they saw as being beneficial or effective within the unit: *successful introduction to engineering*, *engineering design process and habits-of-mind*, *authenticity*, *motivation and purposefulness*, *student ideas,* and *student accomplishment.* Conversely, they also discussed at least four primary areas of improvement: *facilitating teamwork*, *adhering to design specifications and constraints, involving expert engineers throughout the process*, and *timing.* With regard to "timing," the educators discussed how the unit's time-management could have been improved in two ways: its *pacing* and the *time available for failure and iteration*. To provide the reader with a more comprehensive of overview how the primary themes and sub-themes related to and nested within each other, Figure 5.1 provides a schematic of these themes.

As this summary of themes might suggest, in many ways, the educators' views on important teaching priorities and strategies very much paralleled their salient impressions of the PBSL engineering unit. For example, the educators seemed to value exposure to engineering as an important feature that should be the anchor to any pre-college engineering unit, and they also noted that one of the positive aspects of the assistive-device PBSL engineering unit was that it successfully introduced students to engineering. This was similarly true for several other themes centering around the engineering design process, designing within constraints and specifications, valuing and encouraging student ideas, allowing room for mistakes and failure, teamwork, and involving expert engineers. Thus, it is likely that the educators' general instructional priorities and valued strategies may have informed their impressions and assessments of the unit, and vice versa.

Figure 5.1

Schematic of Themes and Sub-Themes of Educator Perspectives



CHAPTER SIX:
DISCUSSION

After having reviewed the salient findings emergent across the student and educator perspectives, this chapter aims to synthesize and interpret these findings within the context of the guiding research questions and the broader literature. As such, it first directly addresses and discusses the study's findings in relation to the three research questions. It then comments on the role of the school setting particularly as it related to facilitating a project-based service-learning (PBSL) engineering unit. It then concludes with brief commentaries on the implications, limitations, and future directions of this research.

Research Question 1: PBSL Engineering Design Units, Students' Sense of Purpose in Life, and Their Perceptions of and Interests in Engineering

The objective of this discussion is to offer insights as to how the findings presented in Chapter Four address the first research question, "How, if at all, does participation in an engineering design PBSL unit contribute to middle school students' sense of purpose in life and their perceptions of and interests in engineering?" It thus synthesizes the findings on the student perspectives related to this question and situates them within the literature to better understand what role the PBSL engineering unit may have played. Additionally, it will examine the importance of agency in purpose development.

Students' Sense of purpose in life

As noted in Chapter Four, at least nine of the 13 student interview participants indicated that they had at least a partial, if not strong, sense of their purpose-in-life. This suggests that even at their young age of 11 or 12 years old, students are beginning to contemplate their purpose-in-life and develop notions of a broader existential purpose. This was also evident in the definitions they offered in explaining what they believed the concept of "purpose-in-life meant." Firstly, in describing their notions of purpose-in-life, students seemed to discuss purpose either in personal terms or universal terms. That is, they saw having an existential purpose as applying to themselves as well as extending to all persons. Their recognition of purpose as inherent to a person's existence is significant because it shows that students are indeed beginning to develop and contemplate deeper existential ideas, such as the concepts of purpose and meaning in life. Indeed, the growing body of empirical research on childhood and adolescent purpose show that these nascent ideas of purpose among youth are worth attending to because they often are the precursors to a person identifying and committing to a purpose-in-life (Bronk, 2014). As Bronk (2014) notes, "While people can develop a purpose any time after late childhood, research suggests that purposeful activity often begins during childhood, becomes intentional and meaningful during adolescence and emerging adulthood, and evolves throughout midlife and later adulthood" (p. 69). Thus, this late childhood/early adolescent stage is a critical point in youth purpose development. As it concerns the present research, the age range of the participating students (11–12 years old) was thus, in many ways, an optimal time to introduce and explore project-based service-learning within the context of early engineering experiences. That is, it is important to consider how early STEM learning experiences and pedagogies, such as PBSL, can contribute to the purpose explorations that students at this developmental stage are beginning to contemplate and engage in.

Before endeavoring to pronounce on whether and how the PBSL engineering unit contributed to students' sense of purpose, it is first helpful to examine how students' notions of purpose-in-life aligned with the theoretical definition of purpose as offered in the literature. The purpose construct is defined by three primary qualities: it has a beyond-the-self orientation and contribution, it is personally meaningful to the individual, and it is a far-reaching and enduring goal (Bronk, 2014; Damon et al., 2003). With this framework for purpose in mind, we can examine the student interviewee's discussion of purpose, particularly their own sense of purpose in life, and how the PBSL engineering unit might have contributed to these notions.

One important aspect of students' notions of purpose was their associations of purpose with the ways in which one might contribute to society or make a difference or an impact in the world. These definitions of purpose signaled that students inherently recognized the fundamental quality of purpose as a having a beyond-the-self contribution (Bronk, 2014; Damon et al., 2003). Similarly, almost all students either expressed a sense of social purpose or socially purposeful goals or interests, particularly in altruistic terms of a desire to help others. This suggested that students saw socially purposeful activity or work (i.e., altruism) as being a key way to contribute to the world beyond-the-self. This is consistent with past research that shows that altruism and socially purposeful inclinations are closely linked to purpose development in youth (Bronk, 2014; Schwartz et al., 2009).

As it pertained to the PBSL engineering unit, 10 of the 13 student interviewees noted that the unit did impact their sense of purpose in life, particularly because of the socially purposeful aspects of the unit. More specifically, students discussed how the design challenge's orientation toward helping people within their community encouraged their further desires and intentions to help others. In this sense, then, students overall perceived the service-learning aspect of the unit, manifested in the assistive device design challenge, as a context within which they had the opportunity to help their community and/or impact it; in so doing, the unit facilitated an opportunity for students to engage in socially purposeful activity that contributed to the world beyond-the-self.

The students also explicitly described the PBSL unit as being meaningful to them. For some students, it was meaningful to them because it was personally important to them to help others. For others, designing assistive devices for arthritis patients was personally significant because they had family members, such as elderly grandparents or parents, who struggled with arthritis. Indeed, some of the students' relatives were among the visiting service-partners. Similarly, students also perceived the unit as being authentic both in terms of helping the community and in doing engineering. In the latter respect, the perceived authenticity of doing engineering was particularly meaningful for those students who had existing interests and aspirations in engineering since the unit afforded an opportunity for students to further explore these interests. While later paragraphs expound in more detail the overall role authenticity seemed to play in shaping students' experiences and perspectives within the unit, overall, the student interviewees seemed to view the unit as being at least somewhat meaningful, particularly in the service objective of the design challenge.

Although some student interviewees expressed inclinations toward socially purposeful goals or other purposeful goals, such as career goals, it is difficult to assess how enduring these goals were, in part because the interview protocol did not directly elicit this data. Furthermore, it was difficult to ascertain whether these goals were existed before the unit or were newly developed and influenced, in part, by the PBSL engineering unit. Although results from the post-unit survey data showed that students generally self-reported at least some sustained effort or engagement toward their goals, these results are not necessarily reliable measures of students' goal-commitment and the longevity of these goals, given that these results only reflect a single self-reported measure. Similarly, it is difficult to gauge whether students' self-reported levels of goal-commitment were related to their purposeful goals or other less-enduring goals.

Nevertheless, given students' developmental stage, it is perhaps less important that students showed strong purpose or goal-commitment at this nascent stage of their purpose-development.

Rather, it was arguably more important that the PBSL engineering unit fostered a context in which students had the opportunity to engage in socially purposeful activity and explore prosocial goals during this early exploration stage. Indeed, as Moran (2018) suggests, recurring community service work or service-learning may ultimately facilitate goal- and purpose-commitment:

> Relationships between purpose and service-learning can be summarized in a feedback-loop model. . . . Community service work is an action aimed to have prosocial effects on other individuals and the common good so it is particularly amenable to demonstrating the model (Moran, 2017b, under review). Even if a student has not already committed to a purpose, community service work could result in feedback on the student's efforts that the student perceives as making a difference in others' well-being, which could generate emotional meaning for the student and generate intentions to contribute in the future. In addition, repeated interactions of meaning, intention and feedback on prosocial effects could catalyze development of a life purpose. (p. 150)

As Moran suggests here, service-learning can serve as a reinforcing mechanism and input for prosocial, or socially purposeful, goals and the development of a broader sense of purpose. Furthermore, as Moran notes, the positive, meaningful "feedback" students receive in contributing toward the common good, encourages students to form similar intentions for the future (Moran, 2018). The student interview data in this study thus demonstrated the veracity of this feedback-loop model because, as recounted in Chapter Four, several students commented that the PBSL engineering unit promoted their desire or interest to continue helping others or contribute to their communities. Thus, given that the PBSL engineering unit did facilitate an opportunity for students to contribute to the world beyond-the-self and participate in a design challenge that was personally meaningful, and afforded a context in which they could explore and engage in socially purposeful goals and activity, project-based service-learning units provide an important learning context that facilitates students' purpose development, even if it may not directly shape their sense of purpose in life.

Social Purposefulness, Engineering, and Possible Selves

It is noteworthy that at least six of the student interviewees associated their sense of purpose with their future career aspirations, often discussing their sense of purpose in terms of what careers they would like to pursue or professional vocations they feel called to. As noted earlier, Bronk (2014) identified career goals and callings as a type of purpose. In this sense then, not only were the students' notions of purpose in this regard again in line with how purpose-in-life is often conceived, but this finding also suggests that as students might be beginning to contemplate their purpose-in-life, they are also considering how their future careers might intersect with their sense of purpose. This, then, has important implications in terms of how students might form ideas of their "future possible selves" and their future career choices.

Recall that Possible Selves theory (Markus & Nurius, 1986) refers to those ideas of oneself that an individual considers to be viable possibilities of what they would like to become or could become. Gottfredson's (1981) parallel theory identifies four processes by which a person may arrive at settling on a career choice. Two of these processes, *self-creation,* or determining ideas and aspirations for oneself particularly as it relates to one' identity, and *circumscription,* or the refining and narrowing of the number of possible aspirations (Gottfredson, 1981), are particularly relevant in understanding how young people's sense of purpose may inform the specific career choice they identify as viable possibilities for their future selves.

These theories offer a helpful lens to interpret the students' perceptions of engineering, particularly as it might relate to their inclinations and aspirations in engineering. Overall, during their post-unit interviews, the students seemed to offer more sophisticated and nuanced definitions and understandings of engineering. As explained in Chapter Four, students described the engineering design process and referred to engineering as inventing or problem-solving, often for socially purposeful aims. That students offered these complex and more accurate definitions of engineering is important because not only did they correspond to the messages about engineering espoused by the professional engineering mentors in this study (as described in Chapter V), but these notions of engineering diverged from past findings on children's typical ideas of engineering.

Past research on young students' notions of engineering showed that, typically, students have ambiguous, inaccurate, or confused perceptions of engineering. For example, Silver and Rushton (2008) analyzed 120 primary school children's drawings of scientists and engineers. Over 65% of their participants drawings of engineers contained an image or a description of an engineer "repairing" something, with over 80% of the pictures depicting engineers as people who fix or work on cars. This indicated that a sizable number of the children in Silver and Rushton's (2008) study believed engineering involved the mending or fixing of something. A similar study by Fralick et al. (2009) examined middle schoolers' notions of engineering; they found that while most drawings of engineers portrayed a human person, nearly one-third of the participants depicted no human at all. Other attributes of engineers depicted in student drawings suggested that the middle schoolers largely conceived of engineers as being "the worker bee," engaging in making or with no action. Fralick et al. (2009) commented on the implications of these student notions of engineering, writing, "Students have inaccurate perceptions of engineering. By focusing on these patterns a powerful image of engineers and engineering is revealed. It is not accurate and is probably a factor in students choosing not to pursue engineering as a career choice" (p. 67).

In light of this past literature, it is thus significant that the students in this present study were able to describe engineering in terms of the engineering design process and to recognize engineering design as aimed at solving problems and improving society. In particular, it is important that students perceived engineering as a socially purposeful profession, because these notions of engineering transcended more typical depictions of engineering as simply repairing broken machinery and rather suggested that students viewed engineers as helping communities in profound ways as a result of their making and inventions. Similarly, students viewing engineering as a socially purposeful profession diverges from, if not subverts, prevalent notions that engineering is a socially-unconcerned profession (see NAE, 2008). Furthermore, such perceptions of engineers as positive contributors to society might encourage students to consider "engineer" as a future possible self, particularly for those students who have a strong sense of social purpose or for whom social purposefulness may be a priority in the self-creation and circumscription processes of determining career aspirations. That is, for students who contemplate and desire a socially purposeful future possible self, they are more likely to consider careers that allow them to positively impact society, and their perceiving engineering as a socially purposeful profession may prompt these students to consider engineering as a viable career and pathway to that goal.

With respect to the PBSL engineering unit, the findings from the student interview data suggest that the unit was influential in helping students develop more interest in engineering as well as these more complex notions of engineering. As noted previously, at least seven of the 13 student interviewees indicated that the unit had some impact on promoting their interest in engineering, while for some of the remaining six students, the unit corresponded to their preexisting interests in engineering. Similarly, 11 of the 13 student interviewees noted that the PBSL engineering unit impacted their understanding of engineering, and several of these students discussed how the project taught them more about the engineering design process. Furthermore, the unit was instrumental in concretizing the socially purposeful aspects of engineering for some students. Ingrid, who explicitly referred to the "arthritis project," reflected that engineering is "helping create something that's going to impact the community or even the world in a big problem." Thus, as Ingrid's comments might indicate, project-based service-learning is a promising pedagogy that can help amplify and define the nuances as well as the socially purposeful aspects of engineering during early engineering education experiences.

Student Agency in Socially Purposeful Engagement

One emergent finding from the student interview data that draws particular significance from the literature on purposefulness and motivation theory is the sense of agency students described regarding their ability to contribute to their communities in socially purposeful ways. Ford and Smith (2007) defined and discussed the role personal agency beliefs (PABs) play in motivation:

> One of the keys to developing and maintaining strong motivational patterns is having a fundamental belief that the future can be better than the present (Snyder, 1994). This requires a belief that there are pathways that can lead to a better future as well as a belief that one has the capabilities and support needed to successfully follow those pathways. In other words, motivation requires faith in one's self as well as faith in the people and resources one depends upon. Such faith is represented in the concept of personal agency beliefs (PABs)... . There are two types of PABs: capability beliefs, which reflect judgments about whether one has the knowledge, skills and biological capabilities needed to attain a goal; and context beliefs, which focus on whether one has the responsive environment needed to attain a goal. (p. 158)

Ford and Smith (2007) explained this link between personal agency and motivation within their Thriving with Social Purpose (TSP) framework, which conceptualizes the relationship between key factors (personal goals, personal agency beliefs, and emotions) that contribute to "optimal human functioning." Within this eponymous framework, Ford and Smith (2007) posited that social purpose is a particularly efficacious element of optimal motivational systems precisely because it combines "engagement and meaning in a single motivational pattern" (p. 164). In other words, social purpose synthesizes integrative social relationship goals, the highest form of personal goals as per Ford and Nichols (1992), with personal agency beliefs, which in turn amplify positive emotions. This creates a powerful reinforcing motivational feedback system (Ford & Smith, 2007).

It is thus significant, then, that in describing their experiences participating in the PBSL engineering unit, the student interviewees used language of ability or capability to describe their potential to contribute their communities. Students saw themselves as being agentic in their socially purposeful goals or aspirations, and some, like Allie, saw engineering as facilitating this sense of agency. Therefore, the PBSL engineering unit was instrumental in facilitating student agency, which is vital to purposefulness and purposeful engagement (Bronk, 2014; Ford & Smith, 2007; Frankl, 1959/2006).

Research Question 2: Educators' Perspectives on Important Features and Instruction Priorities in K–12 engineering PBSL units

The ensuing discussion offers some reflections with respect to the educators' perspectives as they pertained to the second research question that framed this study, "What features and instructional priorities do educators (teachers and mentors) perceive as being important to facilitating an engineering PBSL unit, especially as it relates to promoting youth purpose and interest in engineering?" It begins by briefly addressing the alignment of the educators' perspectives with both the student perspectives and those instructional priorities articulated in the pre-college engineering education literature. It then comments on the expert engineers' reflections on the social purposeful aspects of engineering. Finally, it examines Mrs. Daley's unique positionality within the context of the PBSL engineering unit as a teacher-learner.

Shared Priorities in Pre-College Engineering Education

Although each student and mentor interview occurred individually and independently of one another, interestingly, many of the insights shared by the educators paralleled and corroborated the students' reflections. This was particularly true between the students' notions of engineering and the educators' priority messages about engineering. For example, while the professional engineering mentors espoused messages about engineering that emphasized its design process, problem-solving objective, and potentially socially purposeful nature, students similarly defined and discussed engineering in these terms during their post-unit interviews. Thus, while the engineering mentors may have valued these messages or viewed engineering in this light prior to their participation in the unit by virtue of their expertise in engineering, the PBSL engineering unit reinforced for students, and perhaps directly taught them, similar understandings about the nature of engineering. Indeed, the very involvement of the engineers likely contributed to promulgating these messages organically precisely because the engineers inherently valued these notions of engineering. This is also supported by past research on mentor-mentee relationships between undergraduate engineering students and K–12 students (Houchens, 2010). Houchens (2010) found that undergraduate engineering students serving as mentors to high school seniors during engineering design challenges was an effective model to introduce fundamental concepts about engineering.

In like manner, the educators prioritized instructional features endorsed by frameworks for quality K–12 engineering education present in the pre-college engineering education literature. For instance, Katehi et al. (2009) and Moore et al. (2014) both espoused the importance of teaching the engineering design process and engineering habits of mind; additionally, Moore et al. (2014) emphasized tool-use, problem-solving and analysis, teamwork, and communications related to engineering as essential features of quality K–12 engineering education. The themes from the educator interviews heavily corresponded to many of these same ideas.

An Opportunity for Social-Purpose Reflection for Engineers

As noted in Chapter Five, the mentors embraced the message that engineering can be a socially purposeful endeavor that can positively contribute to society. It should be noted, however, that these reflections from the engineers arose in response to my direct inquiries about their sense of purpose in life, its relationship to their careers as engineers, and the social contributions of engineering. Nevertheless, not only did all three mentors emphatically espouse these points about engineering, but these direct inquiries likely also provided them an opportunity to explicitly reflect on and articulate these aspects of engineering that are all too often obfuscated. Moreover, the purpose literature suggests that it is beneficial for individuals, and in particular, for educators, to explicitly reflect on their own sense of purpose in life, especially in attempting to facilitate purposeful projects for students (Malin, 2018). Given that the direct inquiries embedded in the interview protocol elicited the mentors' reflections on the sense of purpose they derived from engineering, it is worthwhile to consider these and other ways to structure opportunities for more expert engineers to engage in explicit reflections surrounding the purposeful and moral aspects of engineering. Doing so would amplify messages about engineering's socially purposeful potential.

Mrs. Daley as Teacher and Learner

It is interesting that the educators spoke of exposure to engineering at the K–12 level as being important not only for students but for teachers as well. As noted in Chapter Five, Mrs. Daley herself explained that she chose to collaborate on this unit in an effort to gain exposure to engineering and to learn how to teach engineering design at the elementary level; she did not have a strong STEM background and, prior to the unit, felt less confident in her ability to teach engineering. Thus, Mrs. Daley was herself a teacher-learner. In many ways, then, the PBSL engineering unit served as a professional development experience for Mrs. Daley. In working with the engineering mentors, as well as myself, Mrs. Daley reported that she learned more about both engineering and *how to teach* engineering. The unit offered a professional development experience with real-time mentorship in teaching engineering. That is, not only did Mrs. Daley herself have the opportunity to expand her understanding of engineering design, but she was deeply immersed in the design and facilitation of the unit, with support from community members who were able to guide her in enacting best practices in teaching engineering. Furthermore, she learned several teaching strategies, such as implementing budgetary constraints and assigning specific group roles, that she observed in real time as being especially efficacious.

In these ways, this PBSL engineering unit offered a unique model for STEM teacher professional development, as opposed to teachers attending stand-alone sessions or workshops on engineering, which may be more typical of pre-college engineering teacher professional development efforts. This unit exposed Mrs. Daley to important engineering concepts that deepened her own understanding of engineering while also encouraging her to take ownership of the design and enactment of the unit with students within her regular teaching practice. During her interview, Mrs. Daley also expressed that her sense of self-efficacy in teaching engineering greatly improved because of the unit. Indeed, her confidence in teaching engineering so increased that she applied and secured a coveted new position as the Makerspace and Technology teacher within the same school for the subsequent academic year; she later informed me that her participation and learning within the PBSL engineering unit was pivotal in helping her be promoted into this new, exciting role at the school, particularly because she was able to speak of the experience she had gained in teaching related skills and content within the unit.

Research Question 3: Curriculum Design Principles for Purposeful K–12 PBSL Engineering Design Units

One objective of the ecological approach in this study was to ascertain some potential guiding principles for the design of future project-based service-learning and purposeful engineering design units for the pre-college level. In the ensuing paragraphs, then, I synthesize the findings and discussions pertinent to all three research questions, along with my own reflections as a participant-researcher within the study. In so doing, the following discussion introduces some additional excerpts of the student and educator interviews to substantiate the curriculum design recommendations made herein. These guiding principles center around four themes, emphasizing student input, ideas, and hands-on engagement; process over outcome, especially the engineering design process; involving the community; and reflection. It should be noted that these four themes are not intended to serve as an exclusive set of guiding principles for future PBSL engineering design units for the pre-college setting; rather, they merely represent four particularly salient themes from the current study that may facilitate such curricula.

Encourage Student Input, Ideas, and Hands-on Engagement

Echoing some of the educators' key priorities, purposeful, PBSL units in pre-college engineering should centralize student input, ideas, and hands-on engagement. Indeed, with appropriate and sufficient guidance from teachers and other potential mentors, it is particularly crucial that students direct the engineering design process from the outset, not only in later stages. That is, students should have a say in the problem-scoping and identification phase of engineering design. In the present study, it was particularly significant that the anchor problem originated from the students' own problem-scoping and assessment of their community's needs. This allowed students to take ownership of the design challenge from the outset and fostered a sense of meaningfulness for at least some students since the problem was something they themselves observed and was pertinent to loved ones. Furthermore, having students conduct needs assessments within their communities not only inherently valued their input, but it also situated students as active agents within their communities, promoted analytical skills, and fostered their social consciousness. These attributes may serve as important precursors to social purposefulness.

That is, if students are encouraged to closely examine their communities to identify areas of need, decide on which of these needs especially resonate with them, and find ways in which they can serve their community, they are more likely to develop a sense of social purposefulness since they are actively engaging in socially purposeful activity.

Similarly, it is equally imperative for students to be actively involved in the process of contributing solutions to the problems they have scoped and targeted. This entails valuing student creativity in generating viable ideas and concepts for solutions as well as immersing them in the process of realizing these solutions. Students should thus engage in the “messiness” and the “struggle,” as Mr. Aldred often referenced, of translating their ideas into reality; in so doing, students can develop a keener understanding of tool functions and use that would help them achieve these goals. This was also corroborated by the students, several of whom also noted that the opportunity to engage in hands-on activity and working with tools while building and making their prototypes were among their favorite aspects of the project.

Of course, it is worth stating that encouraging student input, ideas, and hands-on engagement does not preclude the parallel input and engagement from teachers and other adult mentors or educators. Indeed, students ought to be intentionally guided throughout all stages by teachers and other mentors in order to help them refine and develop these skills further. However, this guidance should be dialectical and responsive to student ideas, rather than didactic and teacher-initiated. In essence, students should be the primary leaders and directors of PBSL engineering design challenges to the extent possible.

Focus on Process over Outcome

As the engineering education literature has well established, students at all levels should learn and engage in the engineering design process. This point was also unanimously espoused by the engineering mentors in this study. As such, teaching the engineering design process should be a mainstay of any pre-college PBSL engineering unit. Furthermore, in teaching the engineering design process, it is important to hold students accountable to the identified specifications and constraints of the design challenge. Although in the arthritis assistive device challenge, four out of the five design teams ultimately produced at least semi-functional prototypes of assistive devices, at least two groups did not necessarily meet the design specifications or constraints the class had collectively decided upon when developing their project charter during the problem scoping phase. That said, however, it is difficult to determine whether the specifications and constraints in the project charter were perhaps too rigid or could have been amended to allow more flexibility; the student designs that diverged from the specifications in the project charter nevertheless produced innovations that were still assistive to arthritis patients. In any case, PBSL engineering design challenges should have clear, attainable, and developmentally-appropriate design specifications and constraints toward which students must methodically approach through their design process, often through the process of iteration. Design specifications and constraints provide students with clear metrics by which they can continually assess and evaluate their design process against the objectives of the design challenge.

There is, however, one caveat in relation to focusing on process over outcome, particularly in the context of service-learning: since a fundamental principle of service-learning is mutual beneficence in that community partners actually benefit from a service-learning project, it is thus still important that the outcome of a PBSL engineering design challenge produce at least some viable or functional prototypes for the service partners to use. However, having clear design specifications and constraints to guide students' design processes will help ensure that students' designs or prototypes ultimately meet the needs of the community partners they wish to serve.

.Furthermore, the process of students scoping, interacting, and designing for community partners can itself be a valuable service to the community in that students are inherently fostering valuable community ties and relationships by giving of their time and concern to those members of their community who may be in need.

One strategy to scaffold students into deliberating through the engineering design process, particularly with mindfulness toward specifications and constraints, is to incorporate mini-design challenges as precursors to a larger-scale PBSL engineering design unit. This was a strategy that seemed to be especially effective for the arthritis assistive-device engineering design challenge, and one that Mrs. Daley also acknowledged and identified as being valuable. In order to introduce and scaffold student engagement with the engineering design process, we had students participate in a three-day mini-design challenge on building mini wind-mobiles out of craft materials. This challenge provided a good context to introduce collaborative and concept-generating techniques such as the C-Sketch strategy (Shah et al., 2001), which was later used throughout subsequent design challenges. Similarly, to scaffold students into service-learning and designing for other people, we also had students do a mini design challenge on developing an educational board game for the fifth-grade students at their school. In this challenge, we also introduced pseudo-budgetary constraints to help students learn how to manage a budget and design within one. These mini design challenges, then, were valuable in familiarizing students with the design process and allowing them to practice skills that would be especially important for a longer and larger-scale service-learning engineering design process. This repeated engagement with the engineering design process in the contexts of various design challenges also likely contributed to helping students learn the engineering design process and see it as a principal facet of engineering.

Prioritizing process over outcome is not only important for teaching engineering, but further beneficial toward cultivating youth purpose, especially their social purpose. Given that one of the hallmark features of purpose is that it is enduring, the development of purpose is a multidimensional and multidirectional process that requires time (Malin et al., 2014). Thus, curricula that deeply engage students in a process that requires them to assess and contribute to the needs of their community also inherently value the process of developing purpose or at least developing social consciousness. More specifically, as noted in the previous discussion on encouraging student input and ideas, the process of closely examining the various needs of their community and subsequently proposing and developing solutions that meet these needs can illustrate for students the complexity of community problems and societal issues. Such a process necessarily demands patience, persistence, and critical thinking in seeking out viable and effective solutions for such problems.

To this point, valuing such habits of mind and attitudes toward failure, which are key to engineering and purpose development, is also germane to emphasizing the process over outcome. In their respective interviews, both the students and the educators discussed the value of students making mistakes and encountering moments of failure but persisting in their effort to resolve these roadblocks and to persevere through their design process. In fact, Mr. Aldred acknowledged during his interview that failure is a normal part of the engineering design process and innovation and that it was important for students to engage in struggle of persisting through the engineering process for the sake of the struggle. Thus, while leading the unit, particularly in facilitating the "create" phase, both Mrs. Daley and I made sure to explicitly encourage students to persist even if they encountered failure. We directly acknowledged that they would likely encounter moments of failure or setbacks throughout their process, and that while it was perfectly acceptable and valid for them to feel temporarily frustrated, it was important that they persevere and keep iterating or seeking out new and creative solutions within the time allotted. Furthermore, we encouraged them to work with their teams to do so and to leverage the knowledge and expertise of the mentors and other resources to assist them. Thus, in so doing, Mrs. Daley and I sought to expressly embrace and promote these habits of mind within the design process.

These habits of mind, particularly persistence and/or perseverance and collaboration, are not only fundamental to the engineering design process, but they also seem promising for purpose development, especially social purposefulness. Although Malin et al. (2017) noted that, "at this early stage, the goal commitment implied by grit and the goal commitment implied by purpose are not one and the same," and that "gritty perseverance" is not necessarily a prerequisite to purposeful intentions (p. 1212), it nevertheless follows that those young people who learn to persevere and show resilience or grit in their purposeful goals are more likely to have enduring purposeful aims. If one can maintain one's commitment to purposeful goals in spite of temporary setbacks, then the longevity of these goals is likely to be greater.

Involve the Community

Another key recommendation or guiding principle espoused by all stakeholders in this study was to involve and engage various community members throughout the entire design process. Arguably, engaging the community is a distinguishing feature of project-based service-learning, and when coupled with engineering design, PBSL certainly warrants community involvement from multiple perspectives. That is, while the educators roundly endorsed the strategy of involving expert engineers from the early stages of the design process, students similarly desired more communication and contact with the service partners. For example, when asked what she would have liked to have seen more of in the unit, Ivy explained how she would have liked to have engaged with the community partners more so as to get more of their input:

> So, um, what I would've liked to have seen more, because we did have somebody that had arthritis come and test it out, but I would have liked to have like *more* people with arthritis to come and test it out, maybe with different kinds of arthritis. 'Cause I don't remember what type she had, but she had one type. So, like we could have like different types of arthritis, like coming and testing it and we would get different answers possibly.

Ophelia also echoed Ivy's sentiments. Community involvement, then, was not only valued by the educators but also by the students.

Since engineering PBSL is intrinsically oriented toward designing solutions for others, it warrants input from multiple perspectives, particularly when used at the pre-college level. These various sources of input can come from a variety of sources but as this research might demonstrate, there is great benefit to at least including expert, professional, or pre-service engineers and representative members of the target service community or population. The feedback from expert engineers can scaffold young students, who are novices in the engineering design process, into deeper and more methodical engagement with the engineering design process. Expert engineers are also likely to foresee challenges students might encounter and could help students think through analyses and resolutions for setbacks, as they did in the present study.

Similarly, soliciting the feedback of community, or service partners is not only essential to a PBSL project, but in a PBSL engineering design challenge, the community partners are in essence the end-users, and as such, their input as to the helpfulness of the students' designs are perhaps most indicative of the success of the students' designs. More importantly, though, in considering its benefits toward developing students' social purposefulness, it is arguably vital that students have opportunities to directly engage with those community members whom they wish to help. In so doing, students are more likely to directly observe how their work, and specifically their designs, can effect real and positive impacts within their community. This can create a motivational feedback loop that might reinforce socially purposeful goals (Ford & Smith, 2007) and cultivate empathy and compassion, which are correlated with purpose development (Malin et al., 2017).

While involving the community may sound like a lofty goal, one feasible strategy to facilitate this aim is to leverage the immediate school community. Teachers and educators considering implementing PBSL engineering units can potentially solicit assistance and participation from students' families or other members within the school community. Indeed, in the present study, almost all, with the exception of one mentor, the visiting service partners as well as the professional engineering mentors were a part of the school's wider community. In a similar vein, when asked what strategies he might offer in recruiting engineers to serve as mentors in such projects, Mr. Humberto also recommended reaching out to students' parents as well as retired engineers, like himself, within the community. Thus, efforts to involve the community need not be elaborate and complex, but rather it can and perhaps should leverage the human and material resources already present within students' immediate communities, if available.

Incorporate Opportunities for Reflection

Pre-college PBSL engineering design units should incorporate multiple opportunities for student reflection. Firstly, from a theoretical perspective, reflection is recurrently identified as a crucial feature within curriculum frameworks for service-learning (Pritchard & Whitehead, 2004), purposeful projects (Malin, 2018), project-based instruction (Barron et al., 1998), and K–12 engineering education (Katehi et al., 2009). Furthermore, incorporating opportunities for student reflection was also a key component of the PBSL engineering unit in this study. In all, there were approximately four points throughout the unit during which students were required to reflect on their process. Two of these points occurred after the two aforementioned mini design challenges, and another two occurred during and at the conclusion of the students' design process for the arthritis assistive devices. These reflections occurred in various formats: brief surveys Mrs. Daley and I designed on Google Forms, student entries in their science journals, and the final design presentations in which students reflected on their entire design process. Regardless of the format, these reflection assignments were typically structured with specific questions that guided students into thinking about various aspects of their process.

Although students had multiple opportunities to reflect on their process throughout the unit, perhaps one additional way to have improved the unit would have been to integrate even more opportunities for student reflection, targeting a broader scope of reflection. That is, while students had opportunities to explicitly reflect on their design process, perhaps these guided reflection activities ought to have encouraged students to explicitly reflect on their sense of purpose in life as well as on the dynamics of their teamwork and collaboration, as Mr. Aldred suggested during his interview. Given that students at this developmental stage appear to be at least beginning to contemplate and explore their purpose-in-life, encouraging students to explicitly reflect on their purpose can help infuse their learning with meaning and facilitate their purpose development and commitment (Bronk, 2014; Malin, 2018; Yeager & Bundick, 2009; Yeager et al., 2014). Similarly, since both the students and educators identified teamwork as an area of improvement, perhaps one strategy to facilitate more optimal collaborations would be to guide students into closely examining their team dynamics and individual contributions. In so doing, perhaps students might perceive a sense of accountability over their individual behavior or contributions as collaborators, and/or they could potentially identify specific ways in which they could improve their team dynamics.

The Role of the School's Setting

Another important factor that facilitated the implementation of this PBSL engineering unit was the context in which it occurred. More specifically, it is not trivial that the school setting was a private, parochial Catholic school; as such, this setting allowed for certain affordances in curricular freedom.

First, in being a private school, the school was not necessarily beholden to rigid accountability measures such as high-stakes standardized testing or district pacing-guides, although the school and the diocese in which it belonged followed the state curriculum standards. Nevertheless, with less pressure to meet systemic accountability measures, teachers at this school had more curricular freedom and room to explore various teaching strategies or curriculum topics. Furthermore, there was strong administrative support as the principal of the school very much subscribed to project-based instruction and encouraged teachers to explore and adopt such innovative pedagogical practices. In these ways then, Mrs. Daley had the curricular freedom to explore project-based service-learning and integrate engineering design into her courses, and indeed, she was encouraged to do so.

Given that the school was a faith-based, Catholic school, the school prioritized integrating into the curriculum Catholic values and faith-education. As such, this setting lent itself to curriculum espousing community service, care for others, solidarity, and social justice, as these are all facets of Christian thinking and morality. Indeed, as noted in chapter three, in the early stages of the unit, Mrs. Daley and I incorporated lessons on Catholic Social Teaching (CST), a topic outlined in the Religious Education curriculum standards put forth by the diocese. In particular, we discussed CST as a framework and impetus for service-learning. Although we did not have many explicit conversations about purpose-in-life, in the few instances we did discuss this topic, it was again facilitated by the Catholic context of the school. Existential questions such as the purpose of life, particularly as it concerns the relationship between the human person and God, have long been topics of Christian theological and philosophical exploration. As such, in broaching the topic of purpose-in-life and service-learning, one key point of conversation was the fundamental Catholic theological idea that the ultimate purpose of the human person is to know, love, and serve God, and in so doing, the faithful Catholic is also called to serve others (CCC, prologue). Thus, while notions of community service, service-learning, and purpose-in-life are not exclusive to Catholic or Christian thought, they have nevertheless long enjoyed prominence in Catholic thinking and education. This is to say that although a Christian context is not necessarily a prerequisite for purposeful PBSL engineering education, such a setting is likely conducive to service-learning models of teaching by virtue of its presumed and inherent philosophical commitments.

In a similar vein, the school's affiliation with a parish church also lent itself to accessing and partnering with various community members for the project. Many of the community members, such as the professional engineering mentors, community service partners, and even myself, were parish-goers. Similarly, in scoping potential community partners for the service-learning unit, students also dialogued with and assessed the needs of the wider church and parish community. The church, then, offered a wider, embedded, and accessible network of community resources and contexts that were pivotal in the service-learning goals of the unit.

Implications of the Study

One key implication of this study is that project-based service-learning can indeed be used to teach pre-college engineering education, even as early as sixth-grade. This is to say that with adequate scaffolding, time, and mentorship, young students are capable of innovating functional or semi-functional designs that can potentially contribute viable prototype solutions for real community needs. Indeed, engaging students in learning activities such as project-based service-learning engineering design challenges, which allow them to contribute to their communities in authentic ways, can promote students' sense of agency as active contributors in their communities.

In a similar vein, this research also shows that pre- and early-adolescent students are beginning to contemplate deep existential questions, like their purpose-in-life, much of which can be tied to a sense of social purpose and how they intend to impact the world. Here, again, PBSL curricula can provide optimal contexts and possibly create positive-reinforcing feedback loops in which students can explore their socially purposeful intentions and agency in concrete ways. In essence, PBSL engineering curricula promotes purposeful engagement. In so doing, learning may also assume a deeper level of meaningfulness, particularly for those students who have socially purposeful inclinations and interests. This meaningfulness can be especially fostered if PBSL units center around the social interests and concerns students themselves observe and assess as areas of need within their communities.

Finally, PBSL engineering units can concretize the socially purposeful aspects of engineering. This is an important implication, given that past research has found that engineering often suffers a crisis of image in that the general public—youth included—do not often perceive engineering as socially concerned (NAE, 2008). However, pre-college engineering education efforts can counter this misconception by integrating more opportunities for students to directly contribute to and deeply immerse themselves in a design process dedicated to solving societal problems by engaging them in PBSL engineering design challenges. PBSL engineering projects need not be overly complex and ambitious in their aims and can still be valuable if focused on meeting needs within the students' more immediate communities, such as those needs emergent within their families, schools, churches, or neighborhoods. Furthermore, focusing on more local community needs may also facilitate greater involvement and engagement with community members. Regardless of the scope or objectives of the PBSL design challenge, teachers leading such units should strive to involve community members by soliciting the feedback of the relevant community/service partners as well as expert engineers to successfully mentor students through their design process. Additionally, engaging the help of expert engineers may also further concretize the socially purposeful aspects of engineering because students can directly observe and dialogue with expert engineers about how engineers contribute to solving important community problems. Fostering socially purposeful notions of engineering can also promote student interest and future aspirations in engineering, if social purposefulness is a priority for students' career aspirations and/or sense of future possible selves.

Limitations of the Study

A chief limitation of this study was that the participant sample in this study was relatively small and from a single school setting. Furthermore, only 13 (or 54%) of the 24 students who partook in the assistive device PBSL engineering design unit participated in the post-unit survey and interviews, and thus, the student data set was incomplete. As such, the participant sample size and characteristics, then, likely do not represent the entire range of perspectives, especially the student perspectives, on the PBSL engineering design unit, nor are these perspectives likely to be generalizable beyond this one class. Regardless, given the relative lack of research around pre-college project-based service-learning engineering curricula, this study still captures valuable perspectives of multiple stakeholders, including those of young students, that can help the education community better understand the potential value and challenges of such community-based pre-college engineering curricula.

Another important limitation was that the methods used in this study did not permit interpretations of causality between the project-based service-learning engineering unit and students' sense of purpose in life and their perceptions of engineering. Because the study only examined post-unit interview and survey data, but not pre-unit or comparison group data, it was difficult to definitively say how students' sense of purpose in life and their perceptions of engineering did or did not change before and after the unit. Additionally, given that I both helped facilitate the unit and conducted the post-unit interviews, it is possible that my role as a participant-researcher could have unintentionally biased or influenced student perspectives. That said, the post-unit interview protocol did attempt a post-hoc analysis of how the unit may have influenced student perspectives in these regards, by asking them directly how the unit impacted their sense of purpose in life and understandings of engineering. Furthermore, throughout their interviews, students often voluntarily referenced the arthritis assistive-device unit even when they were asked to more generally reflect on these concepts and when they were not prompted to discuss the unit specifically. Similarly, the interview protocol also explicitly and strongly encouraged students to provide their honest answers and reflections; indeed, in order to minimize and mitigate potential biases as a result of my role as a participant-researcher, I began each student interview with emphasizing to students that I truly sought their honest opinions and reflections and the value and importance of such responses to this research. In light of this context then, it would not be a logical leap to suggest that the unit did likely (or at least, potentially) impact students' sense of purpose in life and perceptions of engineering as described in Chapter Four. Nevertheless, despite the lack of definitive causality, this study still offers some empirical insights that can inform the design of pre-college engineering education experiences, especially as the experiences might pertain to the dual goals of fostering youth purpose and promoting understanding and interest in engineering.

The findings of this study are limited in their application in that they may be most relevant to students from a similar context and setting. More specifically, since the participating students and teacher in this research came from a single private, Catholic parochial school, the findings here may be most relevant to students in these type of school settings and are not necessarily broadly generalizable. Nevertheless, it is still important to consider and study the various educational contexts for pre-college engineering education. Non-traditional school settings such as those of private and/or faith-based schools can give further insights into the affordances and constraints present in different school contexts that might help us better understand the viability of STEM education initiatives and curriculum efforts in situ. Furthermore, Catholic schools also serve a non-trivial number of students, and it is therefore important to understand how quality pre-college engineering education can best be designed with these students' needs and contexts in mind.

Finally, on a definitional note, there may be some limitations regarding the extent to which the students' final prototype designs can be constituted as service. As noted previously, service-learning in its strictest sense delineates that the service partners ultimately benefit from the work or final artifacts of a service-learning project (Pritchard & Whitehead, 2004). However, while by the end of the arthritis assistive-device PBSL engineering unit of this study, four of the five student design teams produced at least semi-functional prototypes of assistive devices, the class did not have the opportunity to distribute these prototypes to the service partners. This was due, in part, to the rapid onset of the COVID-19 pandemic in spring 2020, shortly after the culmination of the unit, which impelled national lockdowns and in-person school closures. After the unit, for similar reasons, I did not have the opportunity to interview the different community members who served as the community partners for the project to solicit their perspectives on it. Nevertheless, for the most part, the students' final prototypes did at least have the potential to serve and benefit the community members for whom they were intended because a majority of these prototypes were at least able to perform assistive functions for arthritis patients. Furthermore, the community partners did have an opportunity to directly test the students' prototypes and evaluate their effectiveness as assistive devices for their personal needs. In these ways, then, the students' final prototypes still approximated the targeted service, though not as directly as would have been ideal.

Future Directions for Research

Despite its limitations, this research sets the stage for several avenues of further exploration. First, it is important to more directly examine the potential causal relationships between project-based service-learning in pre-college engineering education and youth purpose development and perceptions of engineering. Future research efforts should endeavor to undertake comparison studies either in a pre-post fashion or between various conditions (i.e., students in traditional science courses vs. students participating in traditional/non-PBSL engineering design challenges vs. students participating in PBSL engineering units). Similarly, it would be interesting to compare how these outcomes might differ across students of different grade levels and/or school settings (i.e., public vs. private vs. charter schools and/or Catholic vs. non-Catholic).

In considering broader issues in STEM education, it would also be interesting to examine how PBSL engineering units with socially purposeful objectives facilitate more equitable participation in STEM, and specifically engineering education. More specifically, while this study did not explicitly disaggregate the data by gender and race/ethnicity, future research ought to explore how more socially purposeful engineering curricula might positively influence and promote the participation of women and underrepresented minorities in engineering. Indeed, past research on undergraduate engineering students suggests that service-learning may be an effective model to promote the participation of women and underrepresented minorities in engineering (Lichenstein et al., 2014); thus it would be important to more closely examine how service-learning can also promote early engineering interests and aspirations among underrepresented populations.

Future research could also expand upon some of the findings originating from the educator perspectives. For instance, given that Mrs. Daley self-reported an improved sense of confidence in teaching engineering, one avenue of further research would be to explore how teachers' facilitation of PBSL engineering design units might promote teacher learning and self-efficacy in teaching engineering. Such research would be especially needed given that past research has shown that though teachers recognize the value of teaching engineering, many teachers feel unsure about their understanding of engineering and thus feel unprepared to teach it (Brophy et al., 2008; Hammack & Ivey, 2019). Further, it might be compelling to examine how teacher learning and professional development in engineering education might benefit from partnering with professional engineering mentors. Conversely, given the value added by the assistance and involvement of the expert engineers who served as mentors during the unit, education researchers ought to better understand how effective partnerships between schools and expert engineers can be established, developed, and sustained. Finally, it would also be interesting to better understand how expert engineers may or may not consider the purposeful, and socially purposeful, implications of their profession. That is, it may be important to understand whether and how engineers perceive engineering to be a career that can promote a sense of purpose in life; in turn, this may inform how future pre-college engineering education curricula target messages about engineering.

Conclusion

This research endeavored to explore how the design and implementation of a project-based service-learning engineering unit at the pre-college level could facilitate youth purposefulness and socially positive views of engineering. In all, the findings of this study show that project-based service-learning engineering curricula hold much potential to contribute to youth purposefulness, especially social purposefulness, and promote more sophisticated as well as socially purposeful notions of engineering. This is likely because PBSL engineering curricula create an authentic context in which students can become purposefully engaged; in so doing, they may also develop a sense of agency about their ability to serve as meaningful contributors in their community. From an educator perspective, PBSL engineering units could also create authentic contexts in which students gain exposure to engineering, can and should meaningfully engage with the engineering design process, and learn appropriate collaborative skills. Furthermore, PBSL engineering curricula at the pre-college level also inherently prompts the involvement of various community members, including community partners and professional engineering mentors. Thus, there are many promising features of project-based service-learning that make it an especially attractive pedagogy through which pre-college engineering education can be taught.

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APPENDIX A:

POST-UNIT SURVEY INSTRUMENT

Engineering Project-based Service-Learning and Purpose Survey

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The following survey will ask you a few questions about: yourself; your sense of purpose-in-life; your views about and experiences with participating project-based service-learning; and your interests in engineering.

There are **4 parts** to this survey. Each part contains a set of questions. At the beginning of each part, there will be a brief introduction explaining what that part of the survey is about.

Remember this survey is **CONFIDENTIAL**, and you will **NOT** be graded or judged on your responses. Please respond as *honestly* as possible.

Part 1: In this part of the survey, you will answer questions about your purpose in life as well as your general goals and values in life.

There are **16 questions** in this part. Some questions have multiple questions or statements as part of it. Please try to answer all or most of each question.

Please **read** the directions for each question as well as the question itself carefully.

Select the button that **most closely** describes your own response or feelings toward that question **or type in your answer** in the empty box if there is one.

Please respond as ***honestly*** as possible.

---

1. How clear is your sense of purpose in your life?

- ○ Not at all clear
- ○ A little bit clear
- ○ Somewhat clear
- ○ Quite Clear
- ○ Extremely clear

2. How well do you understand what gives your life meaning?

- ◯ Do not understand at all
- ◯ Understand a little bit
- ◯ Understand somewhat
- ◯ Understand quite well
- ◯ Understand extremely well

---

3. How confident are you that you have discovered a satisfying purpose for your life?

- ◯ Not at all confident
- ◯ Slightly confident
- ◯ Somewhat confident
- ◯ Quite confident
- ◯ Extremely confident

---

4. How clearly do you understand what it is that makes your life feel worthwhile?

- ◯ Not at all clearly
- ◯ A little bit clearly
- ◯ Somewhat clearly
- ◯ Quite clearly
- ◯ Extremely clearly

5. How hard are you working to make your long-term aims or goals a reality?

- ◯ Not at all hard
- ◯ Slightly hard
- ◯ Somewhat hard
- ◯ Quite hard
- ◯ Extremely hard

---

6. How much effort are you putting into making your aims or goals a reality?

- ◯ Almost no effort
- ◯ A little bit of effort
- ◯ Some effort
- ◯ Quite a bit of effort
- ◯ A tremendous amount of effort

---

7. How engaged are you in carrying out the plans that you set for yourself?

- ◯ Not at all engaged
- ◯ Slightly engaged
- ◯ Somewhat engaged
- ◯ Quite engaged
- ◯ Extremely engaged

---

8. What portion of your daily activities move you closer to your long-term aims or goals?

- None of my daily activities
- A few of my daily activities
- Some of my daily activities
- Most of my daily activities
- All of my daily activities

9. How often do you hope to leave the world better than you found it?

- Almost never
- Once in a while
- Sometimes
- Frequently
- Almost all the time

10. How often do you find yourself hoping that you will make a meaningful contribution to or positively impact the broader world?

- Almost never
- Once in a while
- Sometimes
- Frequently
- Almost all the time

11. How important is it for you to make the world a better place in some way?

- ◯ Not at all important
- ◯ Slightly important
- ◯ Somewhat important
- ◯ Quite important
- ◯ Extremely important

---

12. How often do you hope that the work that you do positively influences others?

- ◯ Almost never
- ◯ Once in a while
- ◯ Sometimes
- ◯ Frequently
- ◯ Almost all the time

13. Below is a list of goals that people might want to accomplish during their life. Indicate how important each of the following goals is to you, personally, by selecting the button that best describes your feelings toward that goal (on next page):

	Not at all important to me	**Not very important to me**	**Somewhat unimportant to me**	**Neutral to me**	**Somewhat important to me**	**Very important to me**	**Essential or Extremely important to me**
A. Become successful running my own business							
B. Create things that affect how others think or feel							
C. Take care of the people I'm close to such as family and friends							
D. Be very well off financially							
E. Express myself through the arts							
F. Have a successful career							
G. Get into a high-ranking college							
H. Contribute to solving problems in society or the environment							
I. Have children							
J. Help others							
K. Have a satisfying marriage/relationship							
L. Have a lot of fun							
M. Lead or participate in community-improvement efforts							

	Not at all important to me	Not very important to me	Somewhat unimportant to me	Neutral to me	Somewhat important to me	Very important to me	Essential or Extremely important to me
N. Live an adventurous life							
O. Maintain a physically active lifestyle							
P. Make discoveries or inventions that will do good in the world							
Q. Serve God or a higher power through my actions							
R. Stay connected to my good friends							

14. Think about the most important goals you have for your own life. In a few words, describe ONE goal that is personally very meaningful to you and very important for you to accomplish

____

____

____

15. Briefly describe WHY you want to accomplish this goal:

____

____

____

16. Thinking about **ONLY that goal**, please say how much you agree with the following statements

	Strongly disagree	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**
A. An important reason I want to do this is so my life contributes something positive to the world.					
B. In my free time, I am often doing something that will help me accomplish this goal.					
C. I want to do this because it matches m strengths with something that is needed in the world.					
D. Doing this will give me a sense that my life has purpose.					
E. My strongest motivation for doing this is a desire to do something good for the world.					
F. I am not yet sure what steps I will take to accomplish this goal.					

	Strongly disagree	**Somewhat disagree**	**Neither agree nor disagree**	**Somewhat agree**	**Strongly agree**
G. In the past month, I have often taken action to accomplish this goal.					
H. This goal tells you a lot about what my strongest values are.					
I. This goal represents the kind of person I want to be now and in the future.					

Part 2: This part of the survey asks about your experiences and attitudes regarding the engineering project-based service-learning project you just completed.

There are **3 questions** in this section. Some questions have multiple questions or statements as part of it. Please try to answer all or most of each question.

Answer these questions, keeping in mind how doing the engineering project-based service-learning project impacted your views.

Please read the directions for each question as well as the question itself carefully. **Select the button** that most closely describes your own response or feelings toward that question.

Please respond as *honestly* as possible.

17. The 5 sub-questions in this question are concerned with how meaningful the **engineering project-based service-learning project** you just completed was to you.

Answer these questions, **keeping in mind how doing the engineering project-based service-learning project** impacted your views about how meaningful different aspects of the project was to you. Select the response in each row that best describes your views. (On next page)

	Not at all meaningful	**Slightly meaningful**	**Somewhat meaningful**	**Quite meaningful**	**Extremely meaningful**
A. How meaningful is designing or engineering something to you?					
B. How meaningful is doing a project-based service-learning engineering project to you?					
C. How meaningful is designing something to solve a community problem to you?					
D. How meaningful is designing something to solve someone's problem to you?					
E. How meaningful is using what you learn in class to help the community to you?					

18. After participating in a project-based service-learning engineering project, how likely are you to continue studying engineering in the future?

Very likely

Quite likely

Somewhat likely

Slightly likely

Not at all likely

19. After participating in a project-based service-learning engineering project, how likely are you to pursue an engineering career in the future?

Very likely

Quite likely

Somewhat likely

Slightly likely

Not at all likely

<u>Part 3</u>: The next part of the survey asks about your **current and future interests and career ambitions**, especially as it relates to engineering and other STEM (science, technology, engineering, and math) subjects.

There are **3 questions** in this part.

Please read the directions for each question as well as the question itself carefully. **Select the button** that most closely describes your own response or feelings toward that question.

Remember, you are NOT being graded or judged on your responses. Please respond as *honestly* as possible.

20. We are interested in knowing **<u>why</u>** you would be interested in studying engineering in the future. Please select the button in each row which best describes **how certain you are** about potentially studying engineering or becoming an engineer in the future.

	Definitely not	**Probably not**	**Not sure**	**Probably yes**	**Definitely yes**
A. Do you plan on studying engineering in the future?					
B. Do you plan on studying engineering in college?					
C. Do you plan on being an engineer in your future career?					

21. We are interested in knowing <u>why</u> you would be interested in studying engineering in the future.
Please select the button in each row which best describes **how strong a reason** each statement is as it concerns your interest in a future engineering career (on next page):

	Not a reason	**Minimal reason**	**Not sure**	**Moderate reason**	**Major reason**
A. Technology plays an important role in solving society's problems.					
B. Engineers make more money than most other professionals.					
C. Engineers have contributed greatly to fixing problems in the world.					
D. Engineers are well-paid.					
E. My parent(s) want me to be an engineer.					
F. An engineering degree will guarantee me a job in the future.					
G. A mentor has introduced me to people and					

	Not a reason	Minimal reason	Not sure	Moderate reason	Major reason
opportunities in engineering.					
H. I feel good when I am doing engineering.					
I. I like to build stuff.					
J. I think engineering is fun.					
K. Engineering skills can be used for the good of society.					
L. I think engineering is interesting.					
M. I like to figure out how things work.					
N. My science, technology, engineering, or math class has encouraged and/or inspired me to study engineering.					
O. A teacher, academic counselor, teaching assistant or another adult at school has encouraged and/or inspired me to study engineering.					

	Not a reason	**Minimal reason**	**Not sure**	**Moderate reason**	**Major reason**
P. A school project has encouraged and/or inspired me to study engineering.					

22. The following statements describe potential attitudes to various STEM subjects.
Select the grey button in each row (for each statement) that **best describes how much you agree or disagree** with the statement as it applies to you. (On next page)

	Strongly Disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
A. I am interested in careers that use science.							
B. I like science class.							
C. I am good at science.							
D. I am able to get a good grade in my science class.							
E. I am interested in careers that use math.							
F. I like math class.							
G. I am good at math.							
H. I am able to get a good grade in my math class.							
I. I am interested in careers that use technology.							
J. I like to use technology for class work.							
K. I am able to doell in activities							

that involve technology.							
L. I am able to learn new technologies.							
M. I am good at engineering.							

Part 4: This is the final part of this survey. This part just asks a few questions about yourself.

There are **5 questions** in this part.

Some of them require you to **type in a response** or to **select a response** from a list of options.

23. **What is your full name?**

(Your answer to this question will be kept ***CONFIDENTIAL*** *and will only be used to potentially ask you to participate in a follow-up interview, if you would be willing.)*

____

24. **What school are you in?**

(Your answer to this question will be kept CONFIDENTIAL and will only be used to potentially ask you to participate in a follow-up interview, if you would be willing.)

____

25. **What grade are you in?**

____

26. **What is your gender?**

- ◯ Male
- ◯ Female

27. **What is your race/ethnicity?**

- ◯ White
- ◯ Black or African American
- ◯ American Indian or Alaska Native
- ◯ Asian
- ◯ Hispanic/LatinX
- ◯ Native Hawaiian or Pacific Islander
- ◯ South/Southeastern Asian
- ◯ Mixed race or ethnicities
- ◯ Other
- ◯ Prefer not to say

28. OPTIONAL :

Is there anything else you would like to share about your thoughts about any of the following:
A. your purpose in life and/or values,
B. your experiences doing an engineering project-based service-learning project,
and/or
C. your future career interests?

____

____

APPENDIX B:

INTERVIEW PROTOCOL FOR STUDENTS

1. What did you think of the PBSL (arthritis) project?
    a. What did you like about it?
    b. What didn't you like about it?
    c. What did you learn?
2. How did you feel about designing something for someone who needed your help?
    a. Was that important to you?
3. If I say "purpose in life," what does that phrase mean to you? *
4. Do you think you have a sense of your purpose in life or what it is that you're called to do? What would you say is your purpose in life?
5. Where or in what do you find a sense purpose in life?
    a. Why are these things important to you or how do they help give you purpose in life?*
6. How important is helping others or helping the community to you? To your sense of purpose in life? Explain.
    a. If yes, why is it important to you to help other people or the community?
    b. Do you participate in any activities that already serve the community?
    c. Are there any issues in the community or in society that are important to you? Why is that issue important to you?*
7. Is it important to you that you study or work in a job or a career in the future that brings a sense of purpose in your life?
    a. What sorts of things are most important to you in your learning or in your future job/career?
8. Did your participation in the project-based service-learning engineering project impact your sense of purpose in life? Why or why not?
9. In your own words, what is engineering?
10. When did you first hear or learn about engineering? From whom?
11. Before this project, did you want to be or think about being an engineer?
12. Would you want to study or be an engineer in the future? Why or why not?
    a. What about other careers in STEM (science, technology or math)?
13. Do you see engineering as a career that can help bring you a sense purpose-in-life? Why or why not?
14. Do you see engineering as a career that can help other people or your community?
15. How did the project-based service-learning experience change or impact your understanding of engineering and what engineers do?
    a. Did it help shift your interest in engineering or not really?
16. Anything else?

**Question was added or revised part-way through the interview data-collection period, for later student interviews.*

APPENDIX C:

INTERVIEW PROTOCOL FOR TEACHER

1. How confident do/did you feel about teaching engineering (or, science, technology, math)?
    a. What teacher preparation or professional development have you had that has helped you in teaching engineering?
2. What were your goals for yourself and for your students in teaching engineering (or, science, technology, math)? Why were these goals important to you?
3. How confident do/did you feel about teaching using project-based service-learning?
    a. What teacher preparation or professional development, if any, have you had that has helped you in teaching using project-based service learning?
4. What are your goals for yourself and for your students in teaching PBSL? Why are these goals important to you?
5. What attracts you about teaching with PBSL in teaching the STEM disciplines? What dissuades you about it?
6. How do you think about or usually approach motivating your students in learning science/engineering?
7. What (potential) benefits or pitfalls do you see in using PBSL in teaching the STEM disciplines?
    a. With regard to teaching content?
    b. With regard to motivating students?
8. How do you think or do not think PBSL (potentially) impacted or influenced students' motivation, specifically their sense of purpose and meaning in life?
    a. Have these views changed over time/over the course of the project?
9. How do you think or do not think engineering projects (potentially) impacted or influenced students' motivation, specifically their sense of purpose and meaning in life?
    a. Have these views changed over time/over the course of the project?
10. What were some things that went well or you enjoyed about planning and implementing the PBSL unit/project?
11. What were some challenges or some things you were nervous about during the planning and implementing the PBSL unit/project?
12. What were some key factors that helped contribute to implementing and completing the project?
13. What are some ways you would improve the project if you were to attempt a unit like this again? (Maybe some things you might have wished we had done or not done?)
    a. What advice would you give other teachers thinking about trying a PBSL engineering unit?
14. After participating in this PBSL engineering unit, how likely are you to try teaching another PBSL engineering unit?
15. What role or sense of responsibility, do you see yourself assuming or needing to assume in helping students develop a purpose-in-life?

16. Do/did you take into account how you can help students develop their sense of purpose in life as you planned this project? If yes, how so?
17. Did your own planning and facilitating of a PBSL project impact your own sense of meaning and purpose-in-life? If yes, how so?
18. Did your own planning and facilitating of an engineering project impact your own sense of purpose in life? If yes, how so?
19. How, if at all, has this experience of using PBSL impacted your understanding or views about teaching science, engineering, or other STEM disciplines? Explain.
20. Anything else you'd like to share?

APPENDIX D:

INTERVIEW PROTOCOL FOR MENTORS

1. What were your general impressions participating in the PBSL engineering unit as a mentor?
2. Why were you interested in or motivated to help with mentoring for this project?
    a. Is mentoring generally something you enjoy or is important to you? Explain why or why not?
3. Have you mentored students in a similar capacity before? If yes, explain?
4. How did you see your expertise (in engineering/making, etc.) inform how you mentored students?
5. What did you most enjoy about mentoring students?
6. What was most challenging?
7. As an engineer/maker, what did you want to communicate, demonstrate or otherwise hope students would learn about engineering/your field/your craft?
    a. What do you want students or the youth to know about engineering?
    b. Why was/is this important to you?
8. If you're comfortable sharing, how would you describe your own purpose-in-life?
9. How, if at all, do you see your career (as an engineer, or __________) intersecting with your purpose-in-life?
10. In your own opinion, can engineering promote a sense of purpose in life, generally? If yes, how so?
11. How, if at all, did the PBSL engineering unit succeed in teaching students about engineering? In what ways could it have improved?
    a. Were there any aspects that stood out to you as being particularly strong?
    b. Was there anything you wish you would've seen students doing more of?
12. What advice would you give K–12 educators who want to teach engineering?
13. What advice would you give other mentors who might consider mentoring for a project like this? What would be some important strategies or factors for them to consider?
14. What would be some important factors or strategies to consider in recruiting mentors for future projects like this? How can we increase partnerships like this between expert engineers and schools?

APPENDIX E:

STUDENT TEAM DESIGNS

Team One's Design: Can/Jar Opener

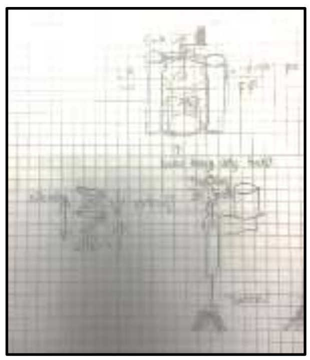
Product Description:

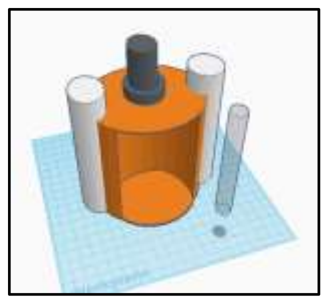
This is a can opener that has a crank mechanism at the top. There is a claw-like gripper extension or tooth that is turned by the crank. This gripper is meant to be able to fit to multiple jar, can, or bottle shapes or sizes (as opposed to a one-size can opener).

Team's Product Description on Mid-Design Survey:

"We are making a product that will help people with arthritis by helping the uncap bottles. We will push a button to open the bottle."

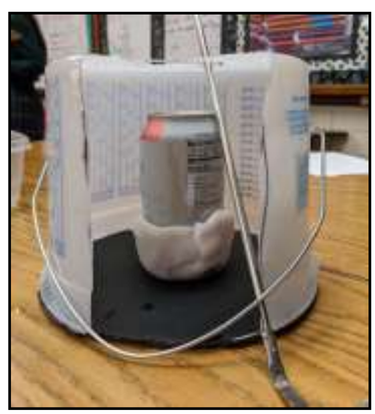
Concept Sketches:





Prototype/Proof of Concept:

Final Functional Prototype:

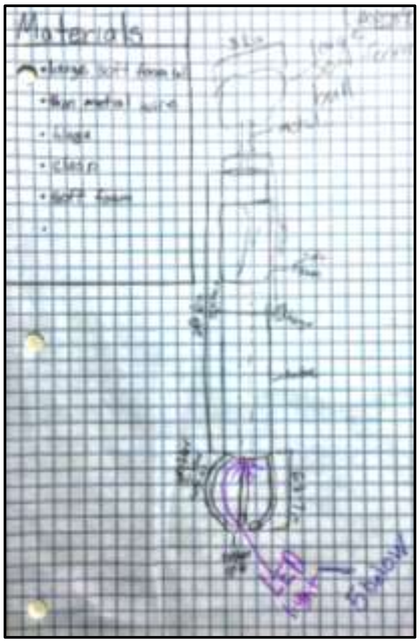


Team Two's Design: Claw Gripper

Team's Product Description on Mid-Design Survey:

"Our design helps with twisting, turning, and grabbing. How it works: You control it by a handle just like a claw machine. If you want to grab something, you press a button and then it will grab it for yourself if you have arthritis."

Concept Sketch:



Prototype/Model of Concept:

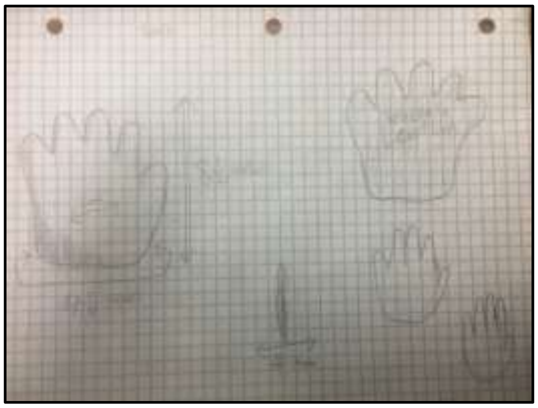
Final Functional Prototype:

Team Three's Design: Arthritis Grip Glove

Team's Product Description on Mid-Design Survey:

"These gloves are soft, durable and flexible. They are used for people who have arthritis."

Concept Sketch:



Prototype/Proof of Concept:

Front of Glove

Back of Glove

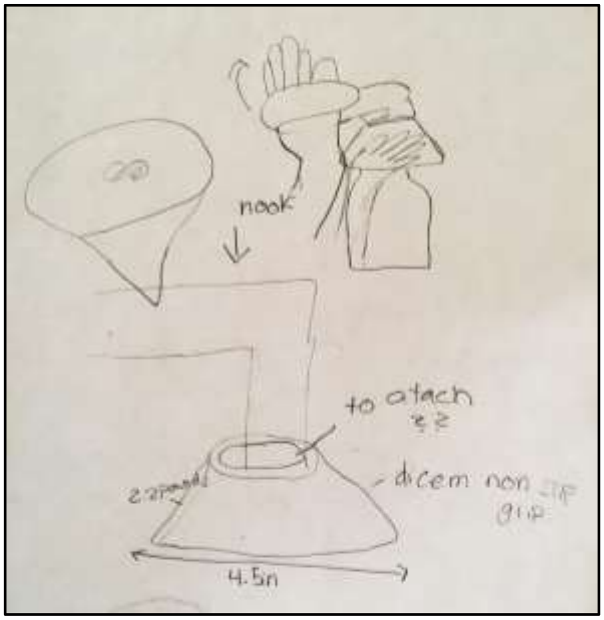
Final Functional Prototype:

Team Four's Design: Dome Gripper

Team's Product Description on Mid-Design Survey:

This team's design features a Dycem gripper dome opener that is supported by a light-bulb changer that is attached to a shaft that is in an "L" shape with a hook at the end that would allow the user to push the shaft to turn the gripping head (sort of like a crank).

Concept Sketch:



Prototype/Model of Concept:

*****Team did not get a chance to build a model of the concept pictured above because team decided to re-design after building model of their initial/first concept.*

Final Functional Prototype:

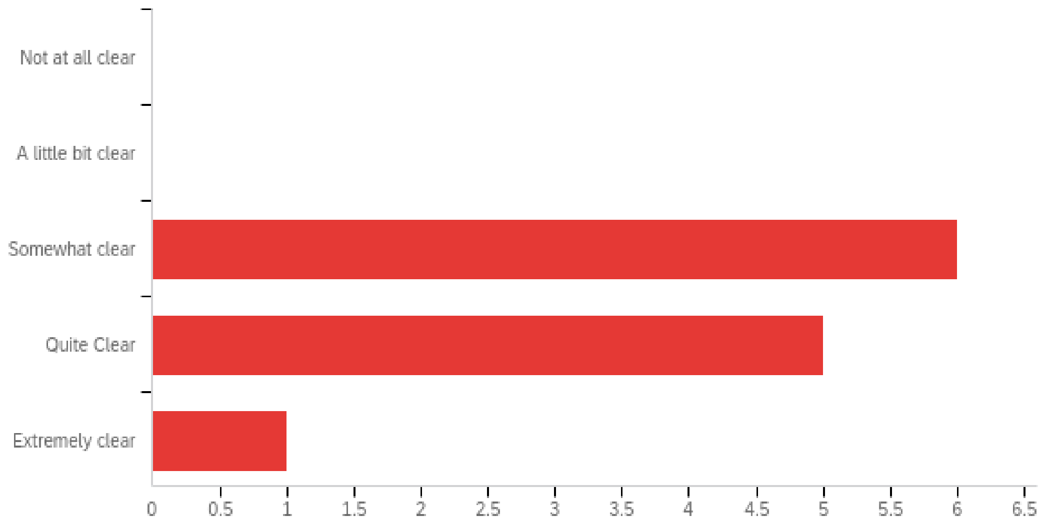
Team Five's Design:

Students in this group did not return assent forms to include their design in the study

APPENDIX F:
COMPLETE RAW SURVEY DATA

Engineering Project-based Service-Learning and Purpose

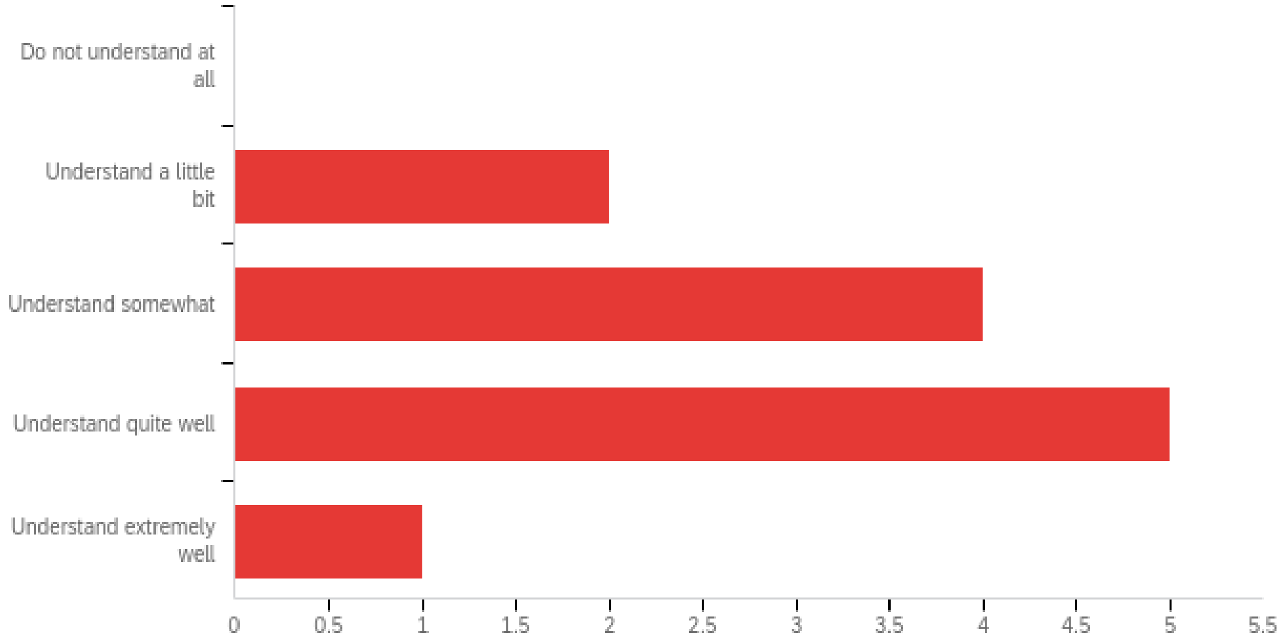
1. How clear is your sense of purpose in your life?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	1. How clear is your sense of purpose in your life?	3.00	5.00	3.58	0.64	0.41	12

#	Answer	%	Count
1	Not at all clear	0.00%	0
2	A little bit clear	0.00%	0
3	Somewhat clear	50.00%	6
4	Quite Clear	41.67%	5
5	Extremely clear	8.33%	1
	Total	100%	12

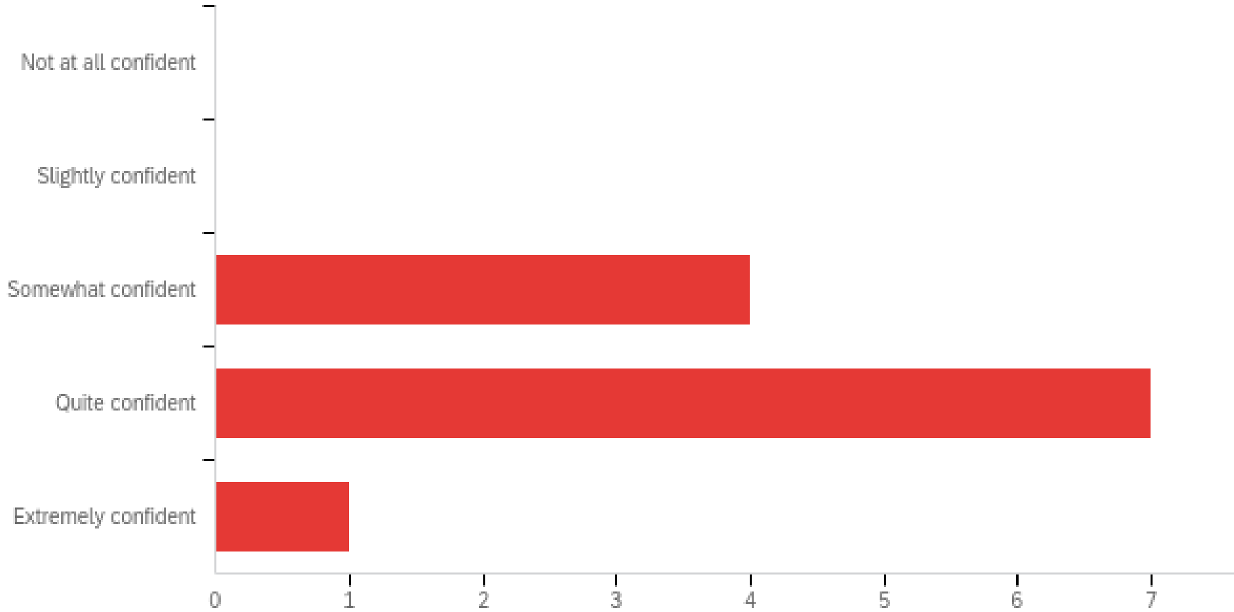
2. How well do you understand what gives your life meaning?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	2. How well do you understand what gives your life meaning?	2.00	5.00	3.42	0.86	0.74	12

#	Answer	%	Count
1	Do not understand at all	0.00%	0
2	Understand a little bit	16.67%	2
3	Understand somewhat	33.33%	4
4	Understand quite well	41.67%	5
5	Understand extremely well	8.33%	1
	Total	100%	12

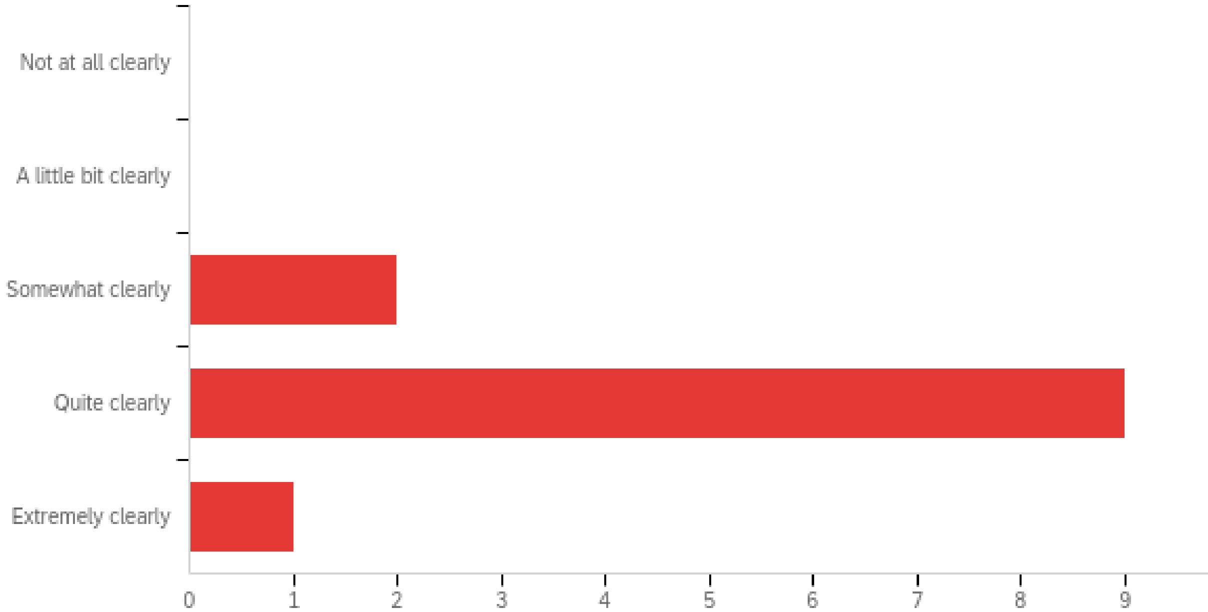
3. How confident are you that you have discovered a satisfying purpose for your life?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	3. How confident are you that you have discovered a satisfying purpose for your life?	3.00	5.00	3.75	0.60	0.35	12

#	Answer	%	Count
1	Not at all confident	0.00%	0
2	Slightly confident	0.00%	0
3	Somewhat confident	33.33%	4
4	Quite confident	58.33%	7
5	Extremely confident	8.33%	1
	Total	100%	12

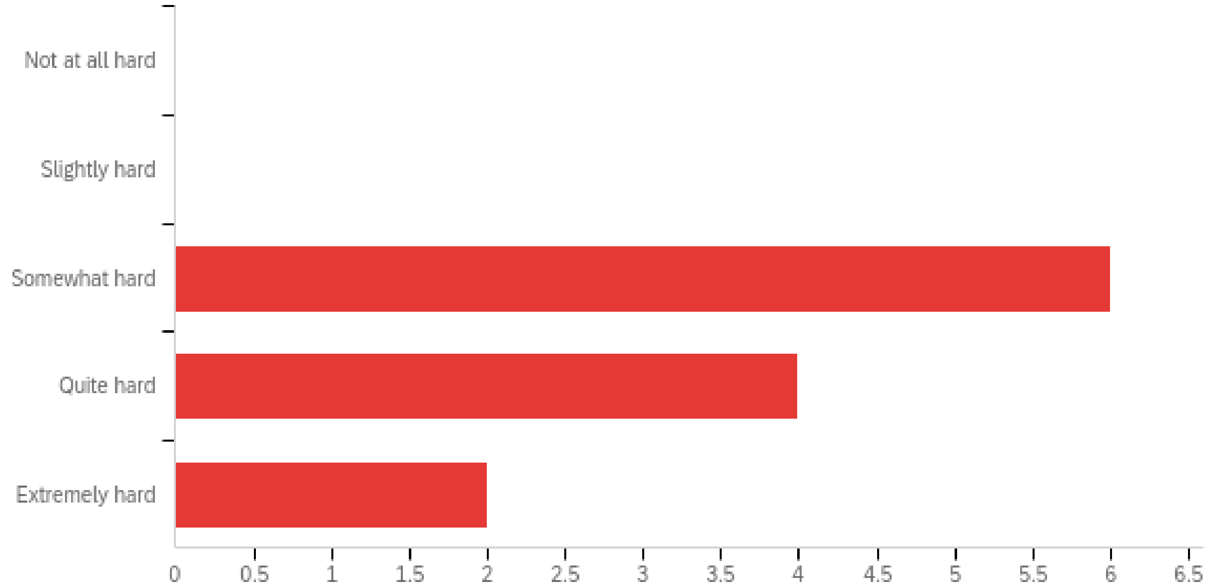
4. How clearly do you understand what it is that makes your life feel worthwhile?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	4. How clearly do you understand what it is that makes your life feel worthwhile?	3.00	5.00	3.92	0.49	0.24	12

#	Answer	%	Count
1	Not at all clearly	0.00%	0
2	A little bit clearly	0.00%	0
3	Somewhat clearly	16.67%	2
4	Quite clearly	75.00%	9
5	Extremely clearly	8.33%	1
	Total	100%	12

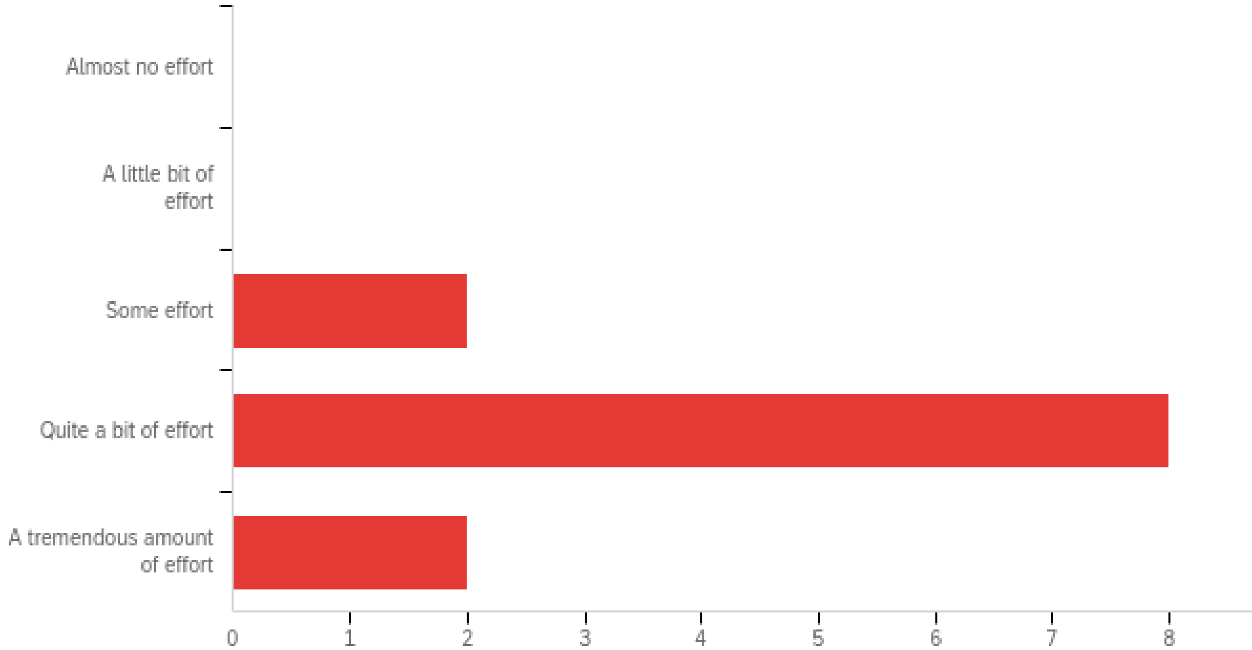
5. How hard are you working to make your long-term aims or goals a reality?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	5. How hard are you working to make your long-term aims or goals a reality?	3.00	5.00	3.67	0.75	0.56	12

#	Answer	%	Count
1	Not at all hard	0.00%	0
2	Slightly hard	0.00%	0
3	Somewhat hard	50.00%	6
4	Quite hard	33.33%	4
5	Extremely hard	16.67%	2
	Total	100%	12

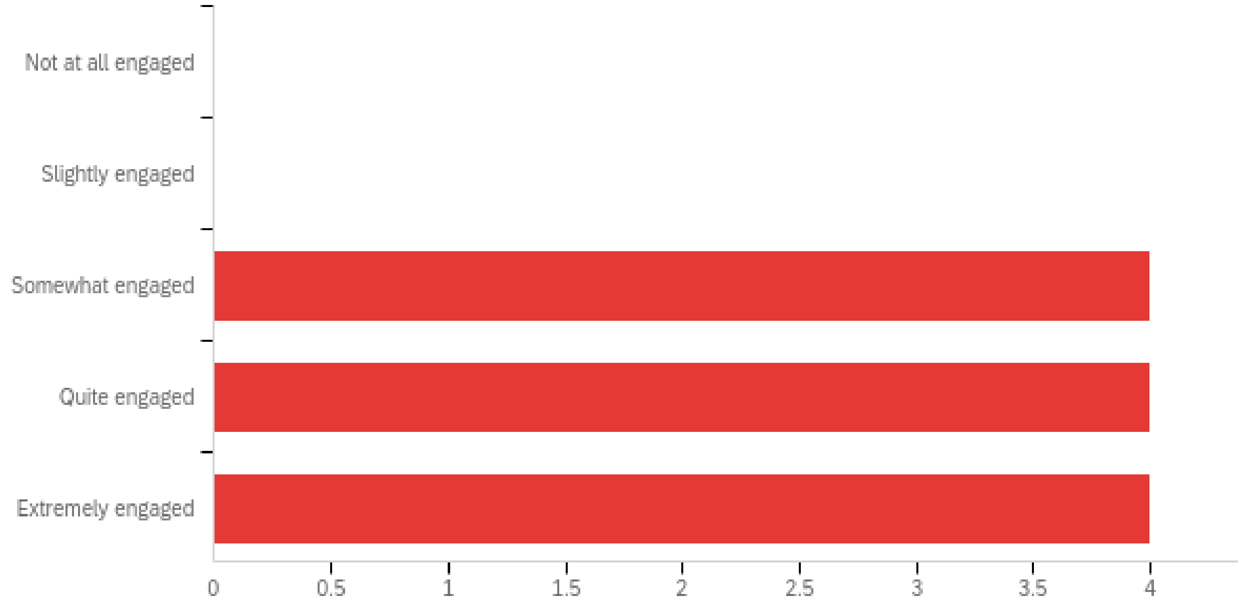
6. How much effort are you putting into making your aims or goals a reality?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	6. How much effort are you putting into making your aims or goals a reality?	3.00	5.00	4.00	0.58	0.33	12

#	Answer	%	Count
1	Almost no effort	0.00%	0
2	A little bit of effort	0.00%	0
3	Some effort	16.67%	2
4	Quite a bit of effort	66.67%	8
5	A tremendous amount of effort	16.67%	2
	Total	100%	12

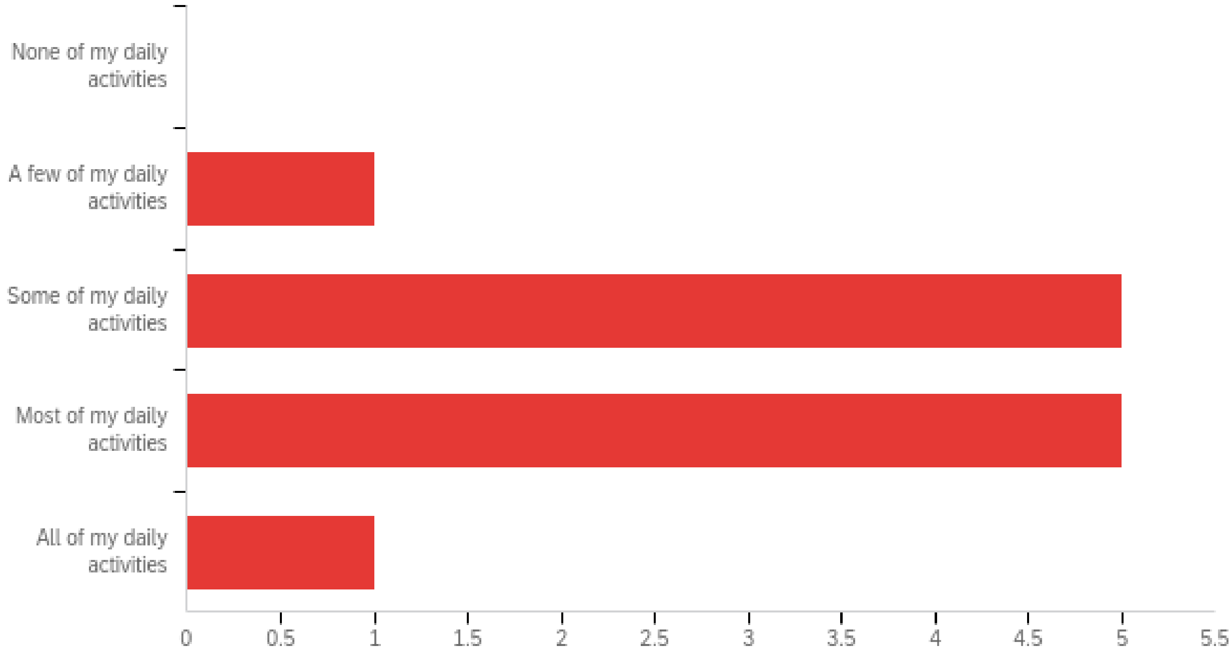
7. How engaged are you in carrying out the plans that you set for yourself?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	7. How engaged are you in carrying out the plans that you set for yourself?	3.00	5.00	4.00	0.82	0.67	12

#	Answer	%	Count
1	Not at all engaged	0.00%	0
2	Slightly engaged	0.00%	0
3	Somewhat engaged	33.33%	4
4	Quite engaged	33.33%	4
5	Extremely engaged	33.33%	4
	Total	100%	12

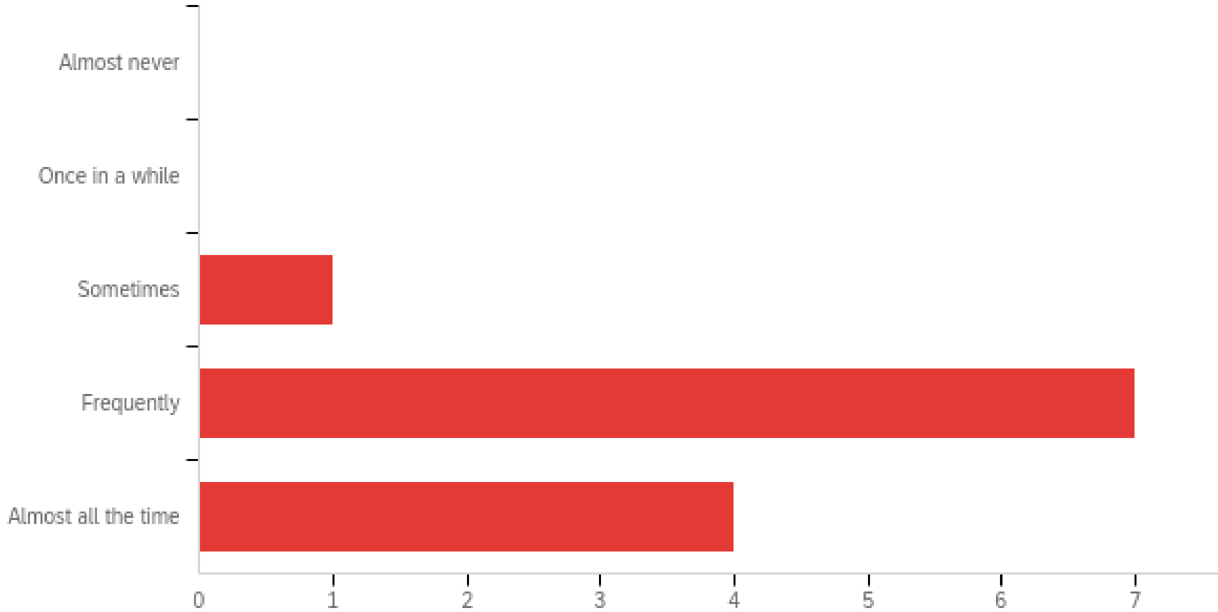
8. What portion of your daily activities move you closer to your long-term aims or goals?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	8. What portion of your daily activities move you closer to your long-term aims or goals?	2.00	5.00	3.50	0.76	0.58	12

#	Answer	%	Count
1	None of my daily activities	0.00%	0
2	A few of my daily activities	8.33%	1
3	Some of my daily activities	41.67%	5
4	Most of my daily activities	41.67%	5
5	All of my daily activities	8.33%	1
	Total	100%	12

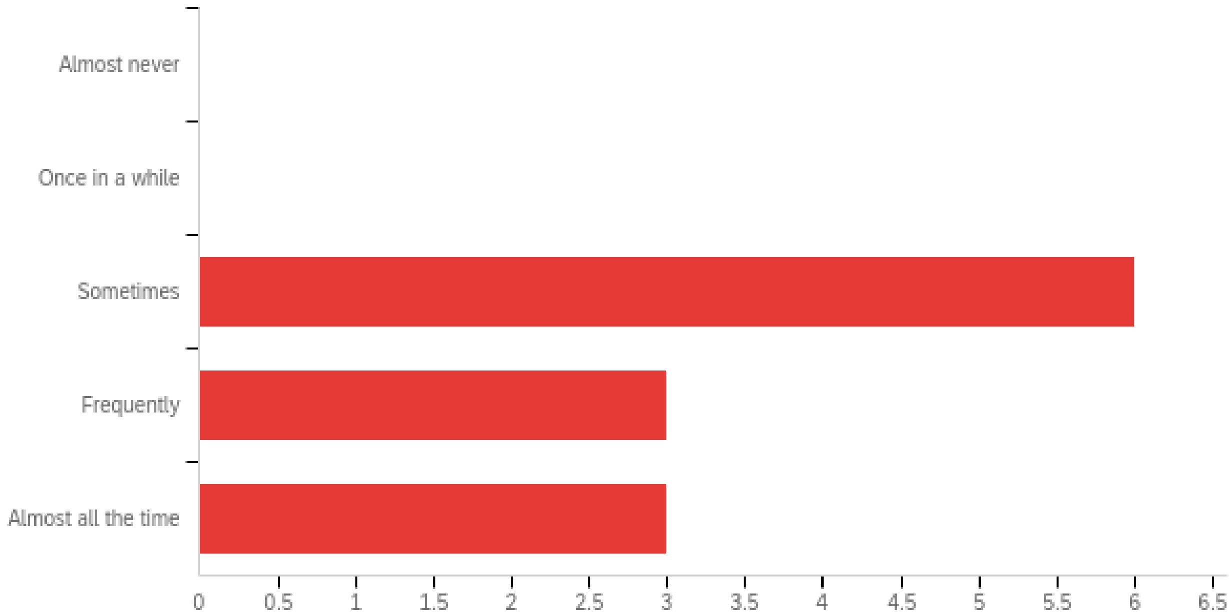
9. How often do you hope to leave the world better than you found it?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	9. How often do you hope to leave the world better than you found it?	3.00	5.00	4.25	0.60	0.35	12

#	Answer	%	Count
1	Almost never	0.00%	0
2	Once in a while	0.00%	0
3	Sometimes	8.33%	1
4	Frequently	58.33%	7
5	Almost all the time	33.33%	4
	Total	100%	12

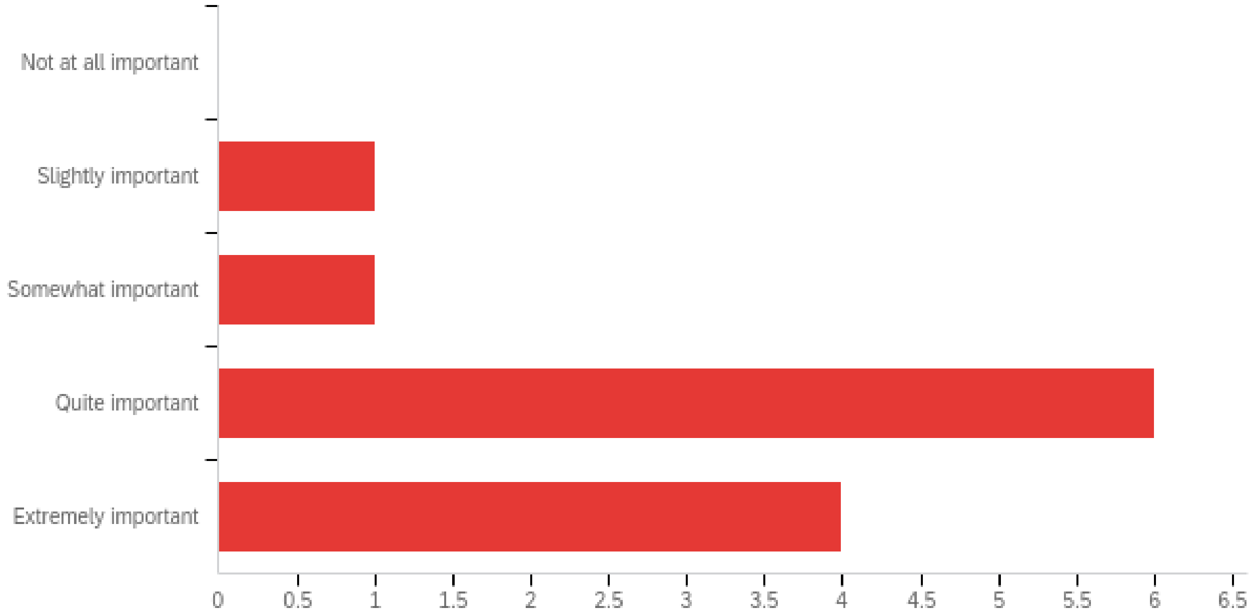
10. How often do you find yourself hoping that you will make a meaningful contribution to or positively impact the broader world?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	10. How often do you find yourself hoping that you will make a meaningful contribution to or positively impact the broader world?	3.00	5.00	3.75	0.83	0.69	12

#	Answer	%	Count
1	Almost never	0.00%	0
2	Once in a while	0.00%	0
3	Sometimes	50.00%	6
4	Frequently	25.00%	3
5	Almost all the time	25.00%	3
	Total	100%	12

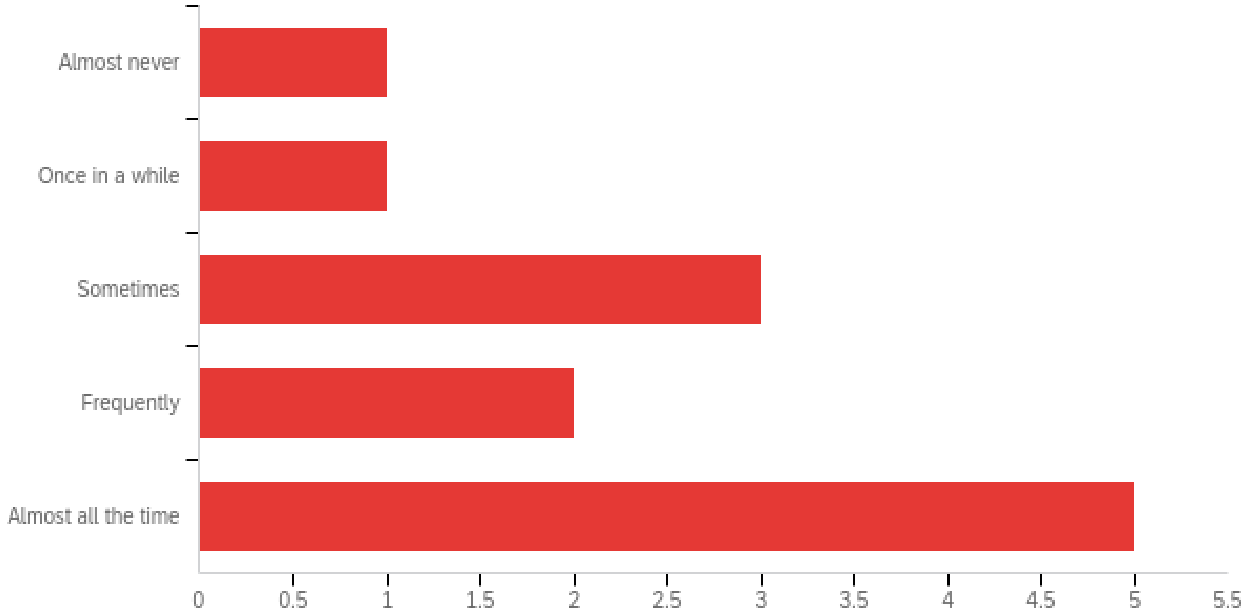
11. How important is it for you to make the world a better place in some way?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	11. How important is it for you to make the world a better place in some way?	2.00	5.00	4.08	0.86	0.74	12

#	Answer	%	Count
1	Not at all important	0.00%	0
2	Slightly important	8.33%	1
3	Somewhat important	8.33%	1
4	Quite important	50.00%	6
5	Extremely important	33.33%	4
	Total	100%	12

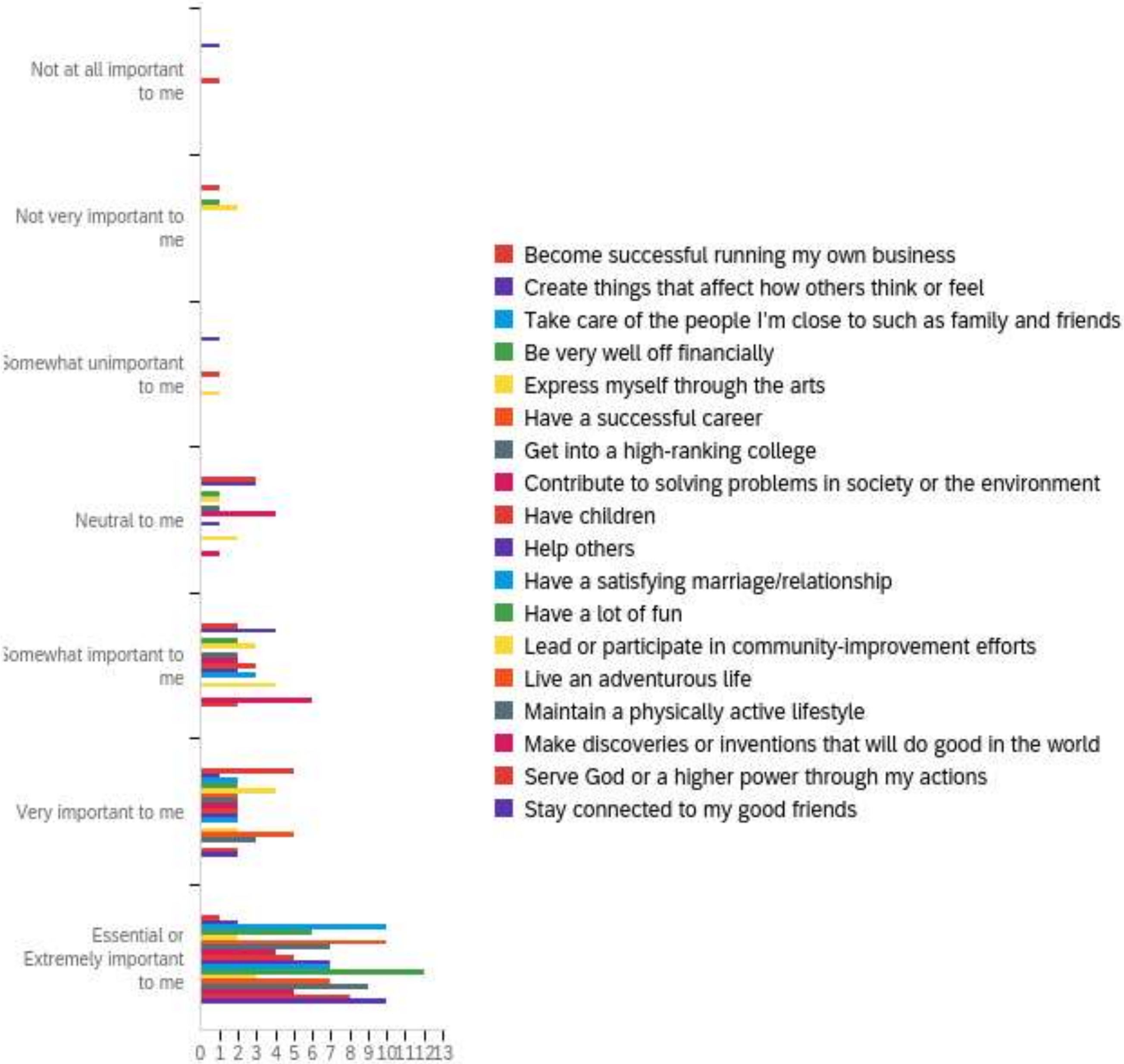
12. How often do you hope that the work that you do positively influences others?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	12. How often do you hope that the work that you do positively influences others?	1.00	5.00	3.75	1.30	1.69	12

#	Answer	%	Count
1	Almost never	8.33%	1
2	Once in a while	8.33%	1
3	Sometimes	25.00%	3
4	Frequently	16.67%	2
5	Almost all the time	41.67%	5
	Total	100%	12

13. Below is a list of goals that people might want to accomplish during their life. Indicate how important each of the following goals is to you, personally, by selecting the button that best describes your feelings toward that goal:



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Become successful running my own business	2.00	7.00	5.08	1.32	1.74	12
2	Create things that affect how others think or feel	1.00	7.00	4.67	1.60	2.56	12
3	Take care of the people I'm close to such as family and friends	6.00	7.00	6.83	0.37	0.14	12
4	Be very well off financially	2.00	7.00	5.83	1.52	2.31	12
5	Express myself through the arts	2.00	7.00	5.08	1.61	2.58	12
6	Have a successful career	6.00	7.00	6.83	0.37	0.14	12
7	Get into a high-ranking college	4.00	7.00	6.25	1.01	1.02	12
8	Contribute to solving problems in society or the environment	4.00	7.00	5.50	1.26	1.58	12
9	Have children	1.00	7.00	5.50	1.80	3.25	12
10	Help others	4.00	7.00	6.25	1.01	1.02	12
11	Have a satisfying marriage/relationship	5.00	7.00	6.33	0.85	0.72	12
12	Have a lot of fun	7.00	7.00	7.00	0.00	0.00	12
13	Lead or participate in community-improvement efforts	3.00	7.00	5.33	1.25	1.56	12
14	Live an adventurous life	6.00	7.00	6.58	0.49	0.24	12
15	Maintain a physically active lifestyle	6.00	7.00	6.75	0.43	0.19	12
16	Make discoveries or inventions that will do good in the world	4.00	7.00	5.75	1.09	1.19	12
17	Serve God or a higher power through my actions	5.00	7.00	6.50	0.76	0.58	12
18	Stay connected to my good friends	6.00	7.00	6.83	0.37	0.14	12

#	Question	Not at all important to me		Not very important to me		Somewhat unimportant to me		Neutral to me		Somewhat important to me		Very important to me		Essential or Extremely important to me		Total
1	Become successful running my own business	0.00%	0	8.33%	1	0.00%	0	25.00%	3	16.67%	2	41.67%	5	8.33%	1	12
2	Create things that affect how others think or feel	8.33%	1	0.00%	0	8.33%	1	25.00%	3	33.33%	4	8.33%	1	16.67%	2	12
3	Take care of the people I’m close to such as family and friends	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	16.67%	2	83.33%	10	12
4	Be very well off financially	0.00%	0	8.33%	1	0.00%	0	8.33%	1	16.67%	2	16.67%	2	50.00%	6	12
5	Express myself through the arts	0.00%	0	16.67%	2	0.00%	0	8.33%	1	25.00%	3	33.33%	4	16.67%	2	12
6	Have a successful career	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	16.67%	2	83.33%	10	12
7	Get into a high-ranking college	0.00%	0	0.00%	0	0.00%	0	8.33%	1	16.67%	2	16.67%	2	58.33%	7	12
8	Contribute to solving problems in society or the environment	0.00%	0	0.00%	0	0.00%	0	33.33%	4	16.67%	2	16.67%	2	33.33%	4	12
9	Have children	8.33%	1	0.00%	0	8.33%	1	0.00%	0	25.00%	3	16.67%	2	41.67%	5	12
10	Help others	0.00%	0	0.00%	0	0.00%	0	8.33%	1	16.67%	2	16.67%	2	58.33%	7	12

#	Question	Not at all important to me		Not very important to me		Somewhat unimportant to me		Neutral to me		Somewhat important to me		Very important to me		Essential or Extremely important to me		Total
11	Have a satisfying marriage/relationship	0.00%	0	0.00%	0	0.00%	0	0.00%	0	25.00%	3	16.67%	2	58.33%	7	12
12	Have a lot of fun	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	100.00%	12	12
13	Lead or participate in community-improvement efforts	0.00%	0	0.00%	0	8.33%	1	16.67%	2	33.33%	4	16.67%	2	25.00%	3	12
14	Live an adventurous life	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	41.67%	5	58.33%	7	12
15	Maintain a physically active lifestyle	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	25.00%	3	75.00%	9	12
16	Make discoveries or inventions that will do good in the world	0.00%	0	0.00%	0	0.00%	0	8.33%	1	50.00%	6	0.00%	0	41.67%	5	12
17	Serve God or a higher power through my actions	0.00%	0	0.00%	0	0.00%	0	0.00%	0	16.67%	2	16.67%	2	66.67%	8	12
18	Stay connected to my good friends	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	16.67%	2	83.33%	10	12

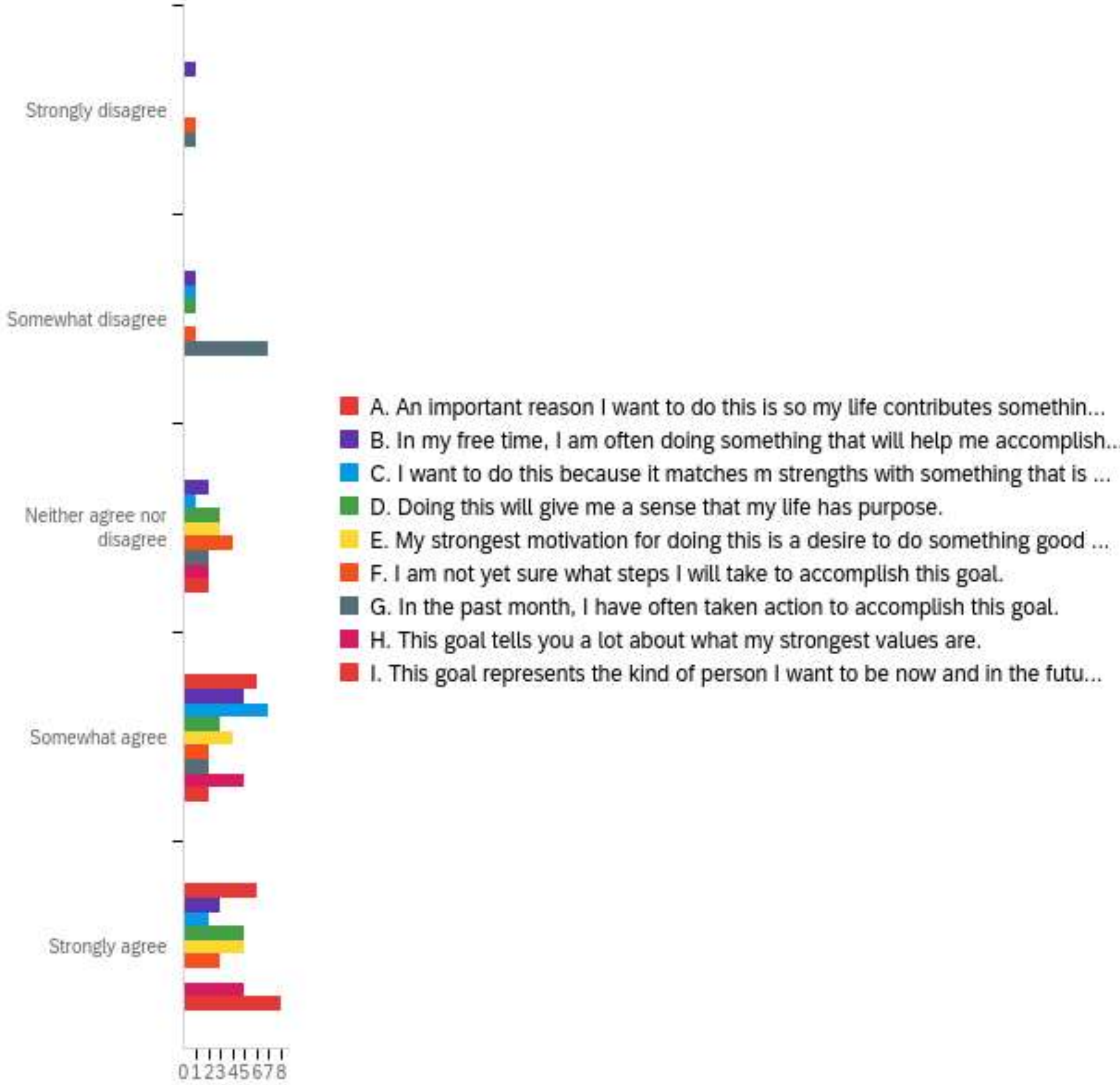
14. Think about the most important goals you have for your own life. In a few words, describe ONE goal that is personally very meaningful to you and very important for you to accomplish

14. Think about the most important goals you have for your own life. In a few words, describe ONE goal that is personally very meaningful to you and very important for you to accomplish
Have a good job
To control my emotions
One goal that I really want to accomplish is to find a way to help teenagers or people in general to achieve what ever they ant to do without worrying what obstacles it has for them.
A goal that is very meaningful to me is to be well off financially but to do good in the world with my money.
have a good job and to me I want that good job to be a race car driver.
Have a successful job and be good person and making the right decisions
Get into a really good collage. and be a pro swimmer
Be a very good and respected entrepreneur.
I want to have a high paying job that I like because I don't want to be poor and so I could feed my family.
have fun and adventures but learn at the same time
become an engineer

15. Briefly describe WHY you want to accomplish this goal:

15. Briefly describe WHY you want to accomplish this goal:
I want to use money yo help others
So i can make friends and help others.
I want to accomplish this goal because it is SUPER important. Not only to me but to society t and o the world. I want teenagers and people to feel and know that they can do anything they put their mind to!
I want to accomplish this goal because I want to help the world but I have to be able to pay for it and support myself too.
because I like cars and going fast
Because so I can help the world become a better place
Because I want to do good in life and i want to do what I live most
Because I am very interested in the subject.
Because I feel like I have to
because being adventurous can open your eyes to new things but while learning so that i can see things how they are meant to be
because it sounds really interesting and fun to me

16. Thinking about ONLY that goal, please say how much you agree with the following statements



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A. An important reason I want to do this is so my life contributes something positive to the world.	4.00	5.00	4.50	0.50	0.25	12

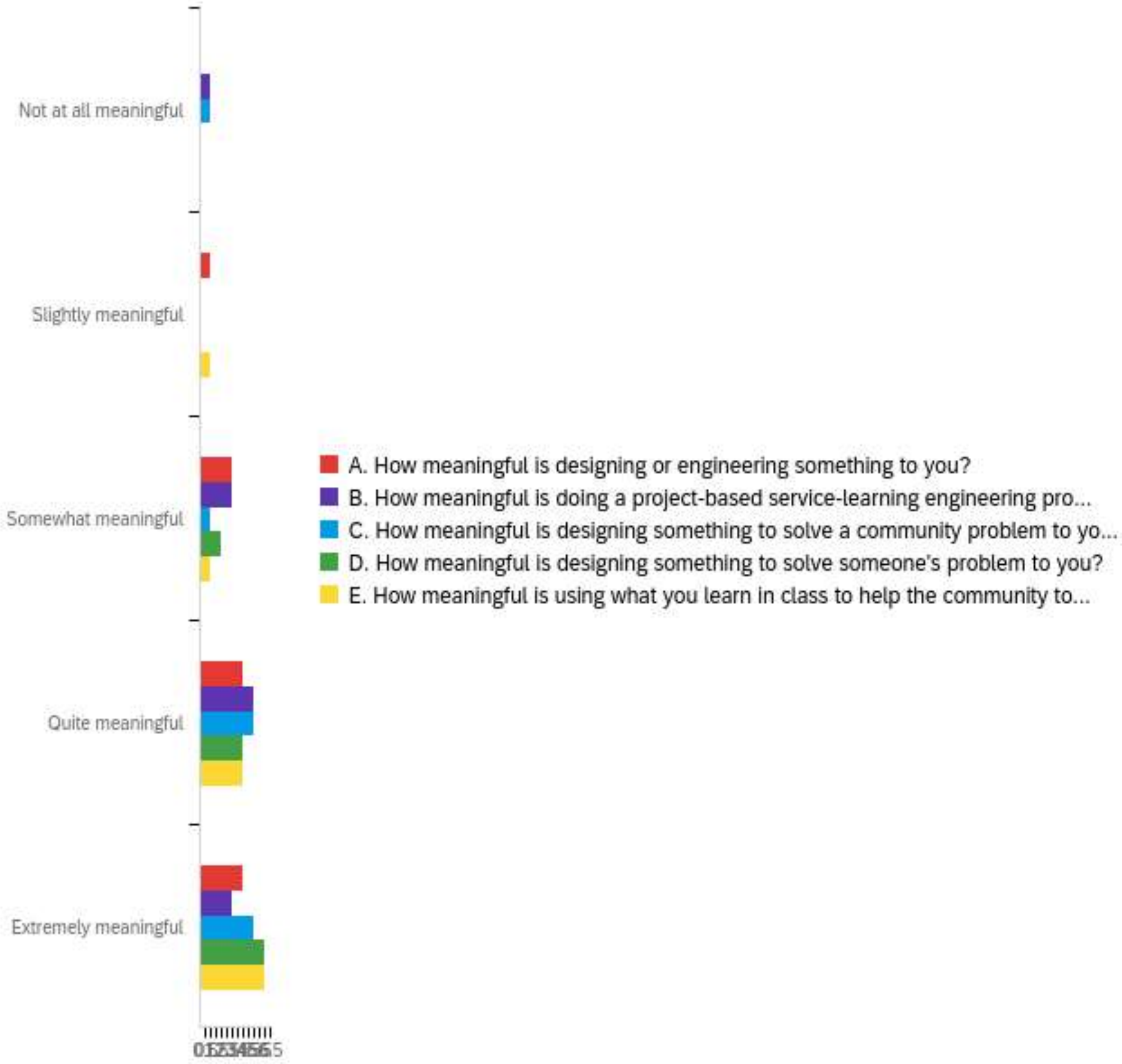
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
2	B. In my free time, I am often doing something that will help me accomplish this goal.	1.00	5.00	3.67	1.18	1.39	12
3	C. I want to do this because it matches m strengths with something that is needed in the world.	2.00	5.00	3.91	0.79	0.63	11
4	D. Doing this will give me a sense that my life has purpose.	2.00	5.00	4.00	1.00	1.00	12
5	E. My strongest motivation for doing this is a desire to do something good for the world.	3.00	5.00	4.17	0.80	0.64	12
6	F. I am not yet sure what steps I will take to accomplish this goal.	1.00	5.00	3.45	1.23	1.52	11
7	G. In the past month, I have often taken action to accomplish this goal.	1.00	4.00	2.42	0.86	0.74	12
8	H. This goal tells you a lot about what my strongest values are.	3.00	5.00	4.25	0.72	0.52	12
9	I. This goal represents the kind of person I want to be now and in the future.	3.00	5.00	4.50	0.76	0.58	12

#	Question	Strongly disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Strongly agree		Total
1	A. An important reason I want to do this is so my life contributes something positive to the world.	0.00%	0	0.00%	0	0.00%	0	50.00%	6	50.00%	6	12
2	B. In my free time, I am often doing something that will help me	8.33%	1	8.33%	1	16.67%	2	41.67%	5	25.00%	3	12

#	Question	Strongly disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Strongly agree		Total
	accomplish this goal.											
3	C. I want to do this because it matches m strengths with something that is needed in the world.	0.00%	0	9.09%	1	9.09%	1	63.64%	7	18.18%	2	11
4	D. Doing this will give me a sense that my life has purpose.	0.00%	0	8.33%	1	25.00%	3	25.00%	3	41.67%	5	12
5	E. My strongest motivation for doing this is a desire to do something good for the world.	0.00%	0	0.00%	0	25.00%	3	33.33%	4	41.67%	5	12
6	F. I am not yet sure what steps I will take to accomplish this goal.	9.09%	1	9.09%	1	36.36%	4	18.18%	2	27.27%	3	11
7	G. In the past month, I have often taken action to accomplish this goal.	8.33%	1	58.33%	7	16.67%	2	16.67%	2	0.00%	0	12
8	H. This goal tells you a lot about what my strongest values are.	0.00%	0	0.00%	0	16.67%	2	41.67%	5	41.67%	5	12

#	Question	Strongly disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Strongly agree		Total
9	I. This goal represents the kind of person I want to be now and in the future.	0.00%	0	0.00%	0	16.67%	2	16.67%	2	66.67%	8	12

17. The 5 sub-questions in this question are concerned with how meaningful the engineering project-based service-learning project you just completed was to you. Answer these questions, keeping in mind how doing the engineering project-based service-learning project impacted your views about how meaningful different aspects of the project was to you. Select the response in each row that best describes your views.

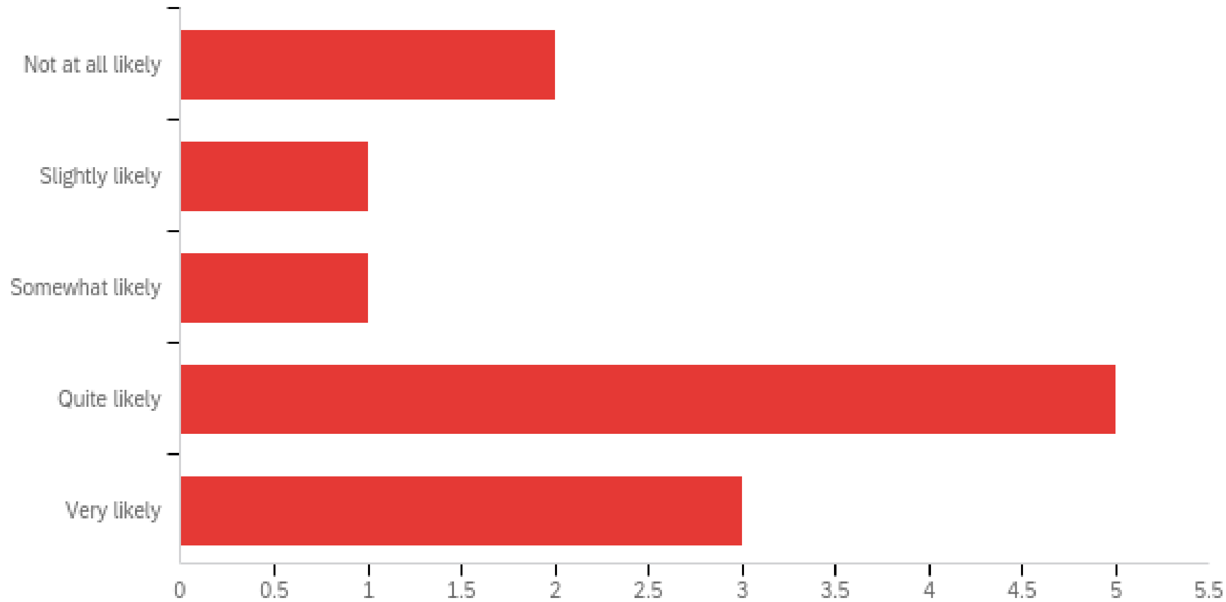


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A. How meaningful is designing or engineering something to you?	2.00	5.00	3.92	0.95	0.91	12
2	B. How meaningful is doing a project-based service-learning engineering project to you?	1.00	5.00	3.75	1.09	1.19	12
3	C. How meaningful is designing something to solve a community problem to you?	1.00	5.00	4.08	1.11	1.24	12
4	D. How meaningful is designing something to solve someone's problem to you?	3.00	5.00	4.33	0.75	0.56	12
5	E. How meaningful is using what you learn in class to help the community to you?	2.00	5.00	4.25	0.92	0.85	12

#	Question	Not at all meaningful		Slightly meaningful		Somewhat meaningful		Quite meaningful		Extremely meaningful		Total
1	A. How meaningful is designing or engineering something to you?	0.00%	0	8.33%	1	25.00%	3	33.33%	4	33.33%	4	12
2	B. How meaningful is doing a project-based service-learning engineering project to you?	8.33%	1	0.00%	0	25.00%	3	41.67%	5	25.00%	3	12
3	C. How meaningful is designing something to solve a communit	8.33%	1	0.00%	0	8.33%	1	41.67%	5	41.67%	5	12

#	Question	Not at all meaningful		Slightly meaningful		Somewhat meaningful		Quite meaningful		Extremely meaningful		Total
	y problem to you?											
4	D. How meaningful is designing something to solve someone's problem to you?	0.00%	0	0.00%	0	16.67%	2	33.33%	4	50.00%	6	12
5	E. How meaningful is using what you learn in class to help the community to you?	0.00%	0	8.33%	1	8.33%	1	33.33%	4	50.00%	6	12

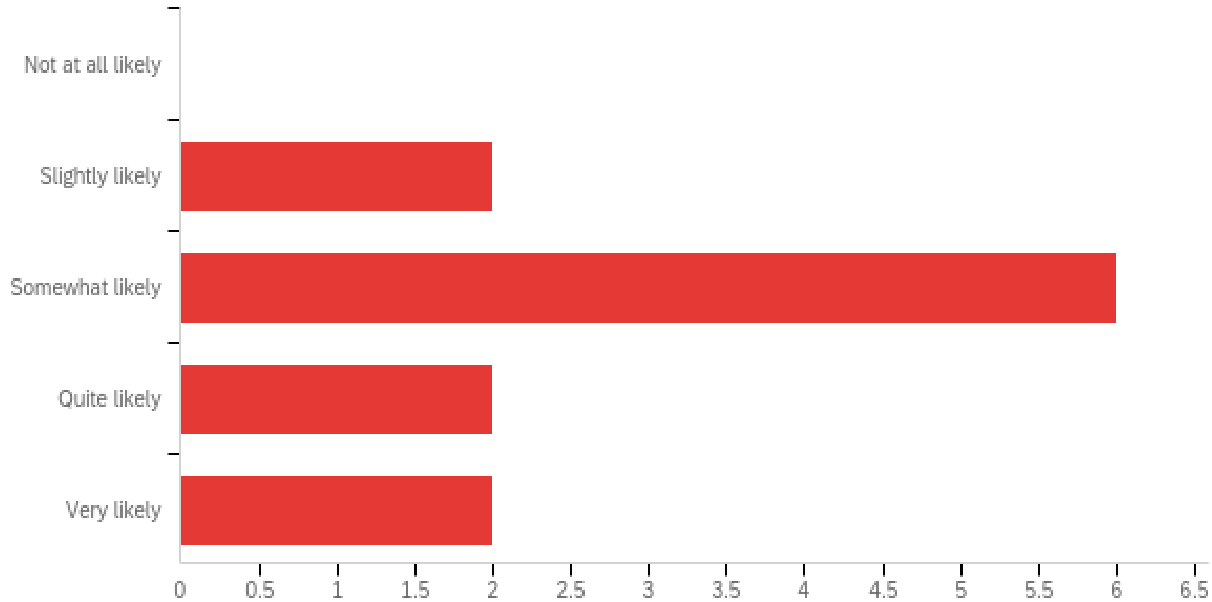
18. After participating in a project-based service-learning engineering project, how likely are you to continue studying engineering in the future?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	18. After participating in a project-based service-learning engineering project, how likely are you to continue studying engineering in the future?	1.00	5.00	3.50	1.38	1.92	12

#	Answer	%	Count
1	Not at all likely	16.67%	2
2	Slightly likely	8.33%	1
3	Somewhat likely	8.33%	1
4	Quite likely	41.67%	5
5	Very likely	25.00%	3
	Total	100%	12

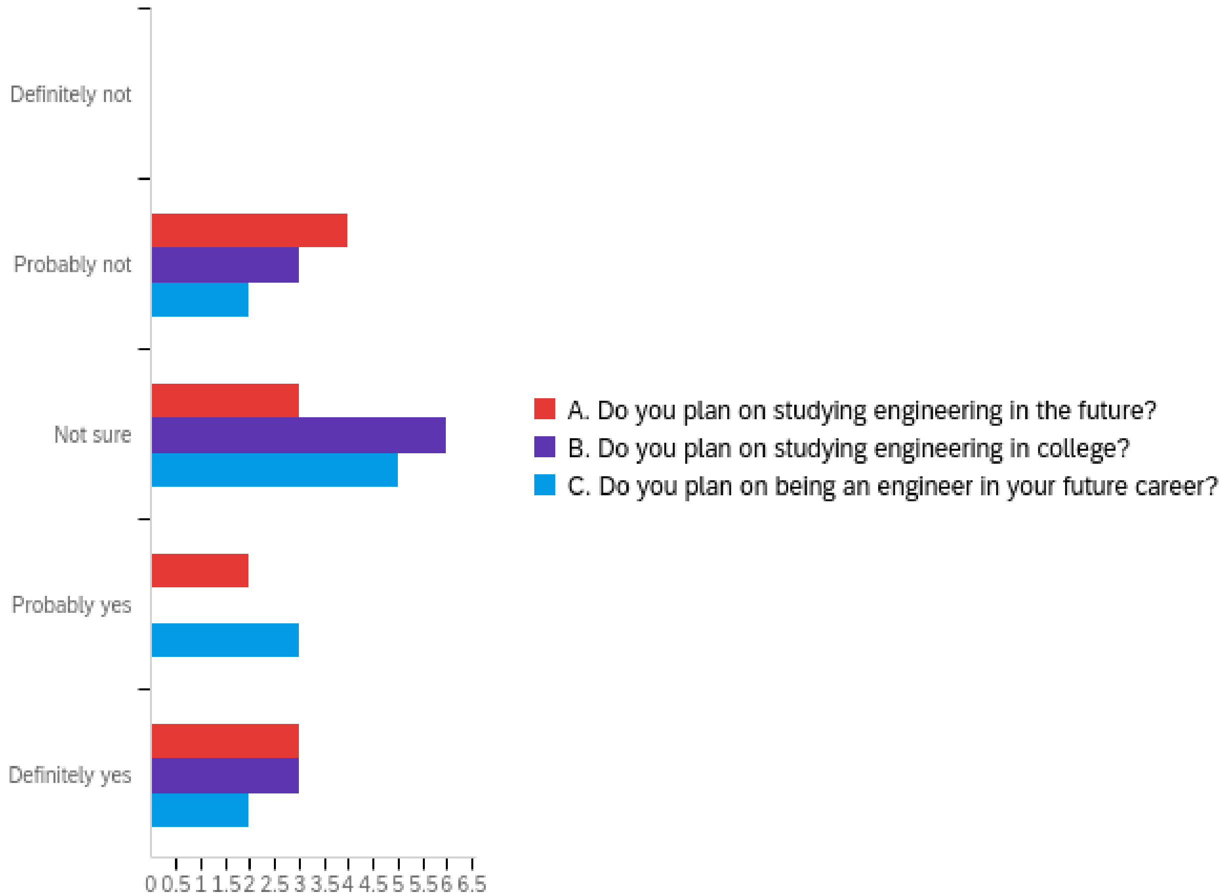
19. After participating in a project-based service-learning engineering project, how likely are you to pursue an engineering career in the future?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	19. After participating in a project-based service-learning engineering project, how likely are you to pursue an engineering career in the future?	2.00	5.00	3.33	0.94	0.89	12

#	Answer	%	Count
1	Not at all likely	0.00%	0
2	Slightly likely	16.67%	2
3	Somewhat likely	50.00%	6
4	Quite likely	16.67%	2
5	Very likely	16.67%	2
	Total	100%	12

20. We are interested in knowing why you would be interested in studying engineering in the future. Please select the button in each row which best describes how certain you are about potentially studying engineering or becoming an engineer in the future.

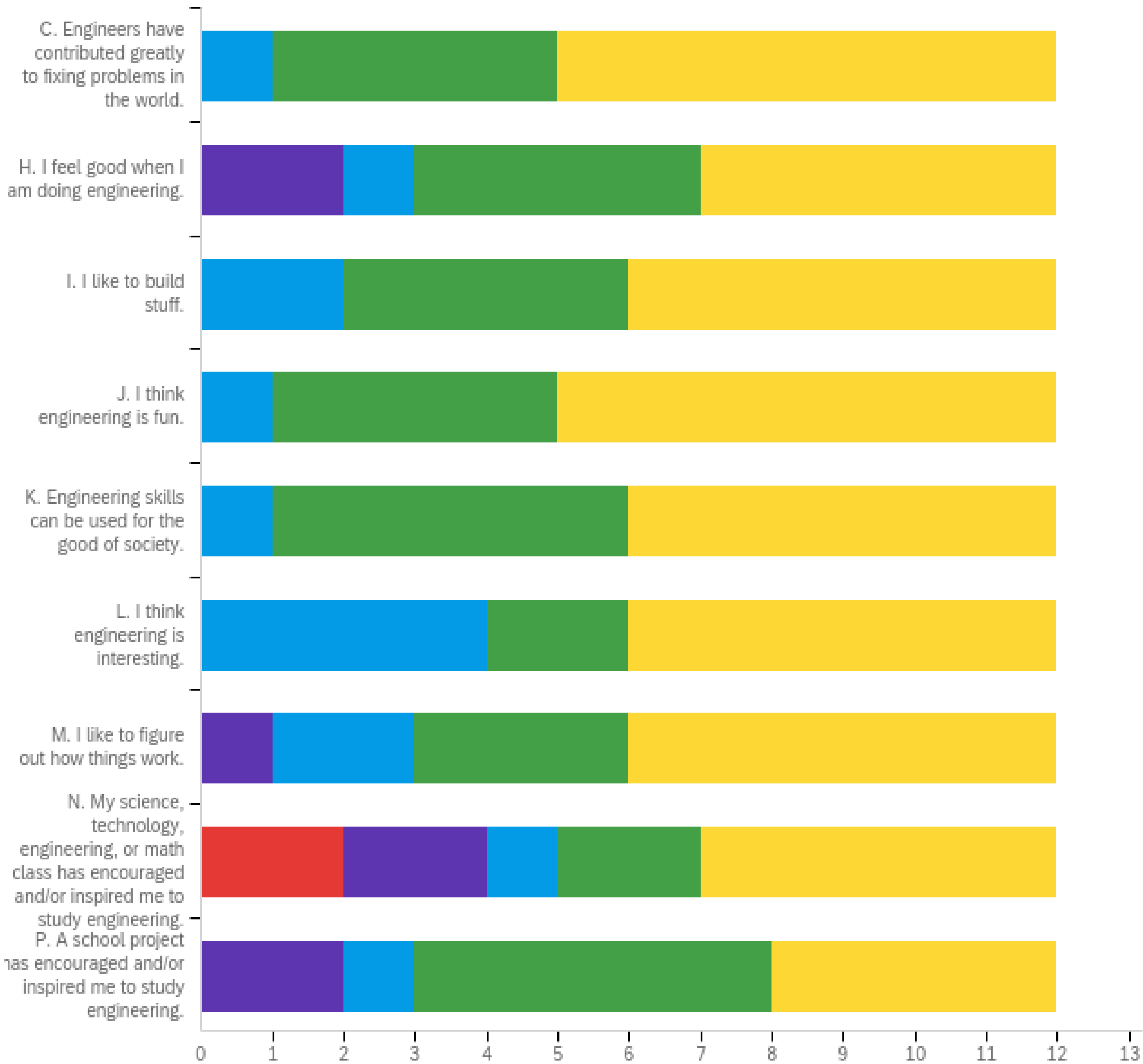


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A. Do you plan on studying engineering in the future?	2.00	5.00	3.33	1.18	1.39	12
2	B. Do you plan on studying engineering in college?	2.00	5.00	3.25	1.09	1.19	12
3	C. Do you plan on being an engineer in your future career?	2.00	5.00	3.42	0.95	0.91	12

#	Question	Definitely not		Probably not		Not sure		Probably yes		Definitely yes		Total
1	A. Do you plan on studying	0.00%	0	33.33%	4	25.00%	3	16.67%	2	25.00%	3	12

	engineering in the future?											
2	B. Do you plan on studying engineering in college?	0.00%	0	25.00%	3	50.00%	6	0.00%	0	25.00%	3	12
3	C. Do you plan on being an engineer in your future career?	0.00%	0	16.67%	2	41.67%	5	25.00%	3	16.67%	2	12

21. We are interested in knowing why you would be interested in studying engineering in the future. Please select the button in each row which best describes how strong a reason each statement is as it concerns your interest in a future engineering career:



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A. Technology plays an important role in solving society's problems.	3.00	5.00	4.00	0.58	0.33	12
2	B. Engineers make more money than most other professionals.	1.00	5.00	2.75	1.09	1.19	12

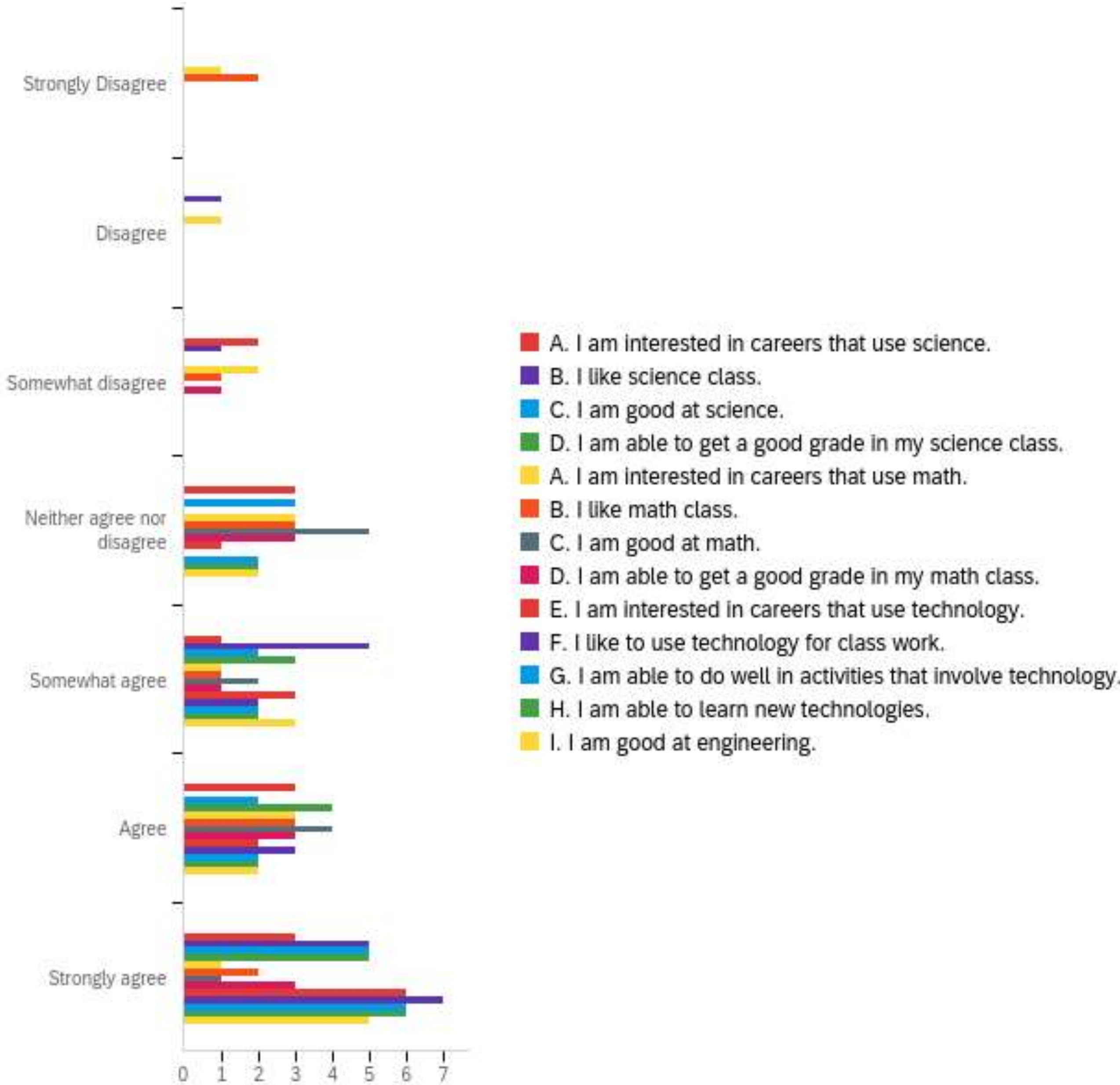
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
3	C. Engineers have contributed greatly to fixing problems in the world.	3.00	5.00	4.50	0.65	0.42	12
4	D. Engineers are well-paid.	1.00	5.00	3.25	1.09	1.19	12
5	E. My parent(s) want me to be an engineer.	1.00	5.00	2.50	1.44	2.08	12
6	F. An engineering degree will guarantee me a job in the future.	1.00	5.00	3.58	1.38	1.91	12
7	G. A mentor has introduced me to people and opportunities in engineering.	1.00	5.00	3.08	0.95	0.91	12
8	H. I feel good when I am doing engineering.	2.00	5.00	4.00	1.08	1.17	12
9	I. I like to build stuff.	3.00	5.00	4.33	0.75	0.56	12
10	J. I think engineering is fun.	3.00	5.00	4.50	0.65	0.42	12
11	K. Engineering skills can be used for the good of society.	3.00	5.00	4.42	0.64	0.41	12
12	L. I think engineering is interesting.	3.00	5.00	4.17	0.90	0.81	12
13	M. I like to figure out how things work.	2.00	5.00	4.17	0.99	0.97	12
14	N. My science, technology, engineering, or math class has encouraged and/or inspired me to study engineering.	1.00	5.00	3.50	1.55	2.42	12
15	O. A teacher, academic counselor, teaching assistant or another adult at school has encouraged and/or inspired me to study engineering.	2.00	5.00	3.58	1.19	1.41	12
16	P. A school project has encouraged and/or inspired me to study engineering.	2.00	5.00	3.92	1.04	1.08	12

#	Question	Not a reason		Minimal reason		Not sure		Moderate reason		Major reason		Total
1	A. Technology plays an important role in solving society's problems.	0.00%	0	0.00%	0	16.67%	2	66.67%	8	16.67%	2	12

#	Question	Not a reason		Minimal reason		Not sure		Moderate reason		Major reason		Total
2	B. Engineers make more money than most other professionals.	16.67%	2	16.67%	2	50.00%	6	8.33%	1	8.33%	1	12
3	C. Engineers have contributed greatly to fixing problems in the world.	0.00%	0	0.00%	0	8.33%	1	33.33%	4	58.33%	7	12
4	D. Engineers are well-paid.	8.33%	1	8.33%	1	50.00%	6	16.67%	2	16.67%	2	12
5	E. My parent(s) want me to be an engineer.	41.67%	5	8.33%	1	16.67%	2	25.00%	3	8.33%	1	12
6	F. An engineering degree will guarantee me a job in the future.	16.67%	2	0.00%	0	25.00%	3	25.00%	3	33.33%	4	12
7	G. A mentor has introduced me to people and opportunities in engineering.	8.33%	1	8.33%	1	58.33%	7	16.67%	2	8.33%	1	12
8	H. I feel good when I am doing engineering.	0.00%	0	16.67%	2	8.33%	1	33.33%	4	41.67%	5	12
9	I. I like to build stuff.	0.00%	0	0.00%	0	16.67%	2	33.33%	4	50.00%	6	12
10	J. I think engineering is fun.	0.00%	0	0.00%	0	8.33%	1	33.33%	4	58.33%	7	12
11	K. Engineering skills can be used for the good of society.	0.00%	0	0.00%	0	8.33%	1	41.67%	5	50.00%	6	12
12	L. I think engineering is interesting.	0.00%	0	0.00%	0	33.33%	4	16.67%	2	50.00%	6	12
13	M. I like to figure out how things work.	0.00%	0	8.33%	1	16.67%	2	25.00%	3	50.00%	6	12
14	N. My science, technology, engineering, or math class has	16.67%	2	16.67%	2	8.33%	1	16.67%	2	41.67%	5	12

#	Question	Not a reason		Minimal reason		Not sure		Moderate reason		Major reason		Total
	encouraged and/or inspired me to study engineering.											
15	O. A teacher, academic counselor, teaching assistant or another adult at school has encouraged and/or inspired me to study engineering.	0.00%	0	25.00%	3	25.00%	3	16.67%	2	33.33%	4	12
16	P. A school project has encouraged and/or inspired me to study engineering.	0.00%	0	16.67%	2	8.33%	1	41.67%	5	33.33%	4	12

22. The following statements describe potential attitudes to various STEM subjects. Select the grey button in each row (for each statement) that best describes how much you agree or disagree with the statement as it applies to you.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A. I am interested in careers that use science.	3.00	7.00	5.17	1.46	2.14	12

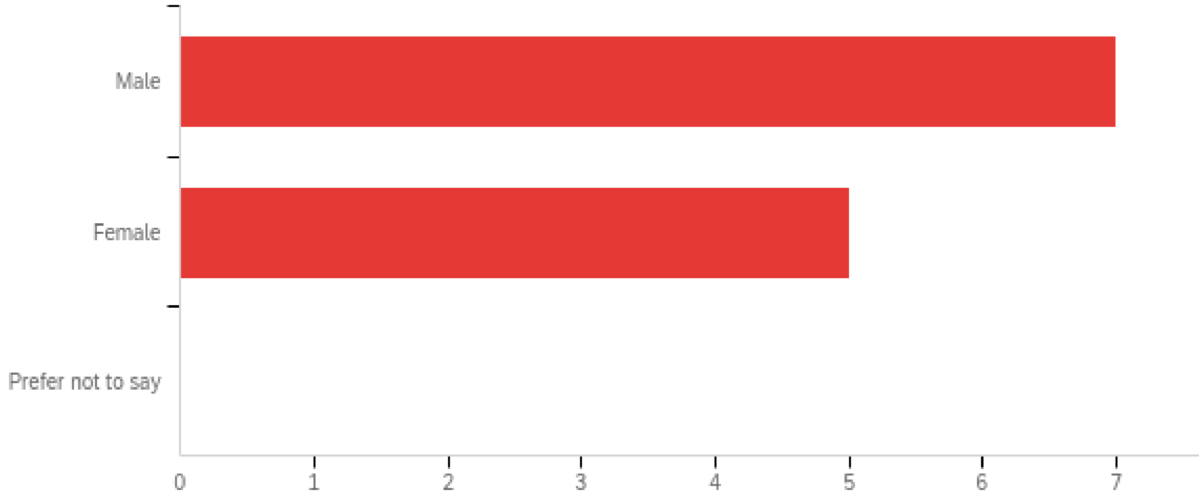
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
2	B. I like science class.	2.00	7.00	5.42	1.61	2.58	12
3	C. I am good at science.	4.00	7.00	5.75	1.23	1.52	12
4	D. I am able to get a good grade in my science class.	5.00	7.00	6.17	0.80	0.64	12
5	A. I am interested in careers that use math.	1.00	7.00	4.25	1.74	3.02	12
6	B. I like math class.	1.00	7.00	4.50	1.98	3.92	12
7	C. I am good at math.	4.00	7.00	5.08	1.04	1.08	12
8	D. I am able to get a good grade in my math class.	3.00	7.00	5.36	1.37	1.87	11
9	E. I am interested in careers that use technology.	4.00	7.00	6.08	1.04	1.08	12
10	F. I like to use technology for class work.	5.00	7.00	6.42	0.76	0.58	12
11	G. I am able to do well in activities that involve technology.	4.00	7.00	6.00	1.15	1.33	12
12	H. I am able to learn new technologies.	4.00	7.00	6.00	1.15	1.33	12
13	I. I am good at engineering.	4.00	7.00	5.83	1.14	1.31	12

#	Question	Strongly Disagree		Disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Agree		Strongly agree		Total
1	A. I am interested in careers that use science.	0.00%	0	0.00%	0	16.67%	2	25.00%	3	8.33%	1	25.00%	3	25.00%	3	12
2	B. I like science class.	0.00%	0	8.33%	1	8.33%	1	0.00%	0	41.67%	5	0.00%	0	41.67%	5	12
3	C. I am good at science.	0.00%	0	0.00%	0	0.00%	0	25.00%	3	16.67%	2	16.67%	2	41.67%	5	12
4	D. I am able to	0.00%	0	0.00%	0	0.00%	0	0.00%	0	25.00%	3	33.33%	4	41.67%	5	12

#	Question	Strongly Disagree		Disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Agree		Strongly agree		Total
	get a good grade in my science class.															
5	A. I am interested in careers that use math.	8.33%	1	8.33%	1	16.67%	2	25.00%	3	8.33%	1	25.00%	3	8.33%	1	12
6	B. I like math class.	16.67%	2	0.00%	0	8.33%	1	25.00%	3	8.33%	1	25.00%	3	16.67%	2	12
7	C. I am good at math.	0.00%	0	0.00%	0	0.00%	0	41.67%	5	16.67%	2	33.33%	4	8.33%	1	12
8	D. I am able to get a good grade in my math class.	0.00%	0	0.00%	0	9.09%	1	27.27%	3	9.09%	1	27.27%	3	27.27%	3	11
9	E. I am interested in careers that use technology.	0.00%	0	0.00%	0	0.00%	0	8.33%	1	25.00%	3	16.67%	2	50.00%	6	12
10	F. I like to use technology for class work.	0.00%	0	0.00%	0	0.00%	0	0.00%	0	16.67%	2	25.00%	3	58.33%	7	12
11	G. I am able to do well in activitie	0.00%	0	0.00%	0	0.00%	0	16.67%	2	16.67%	2	16.67%	2	50.00%	6	12

#	Question	Strongly Disagree		Disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Agree		Strongly agree		Total
	s that involve technology.															
12	H. I am able to learn new technologies.	0.00%	0	0.00%	0	0.00%	0	16.67%	2	16.67%	2	16.67%	2	50.00%	6	12
13	I. I am good at engineering.	0.00%	0	0.00%	0	0.00%	0	16.67%	2	25.00%	3	16.67%	2	41.67%	5	12

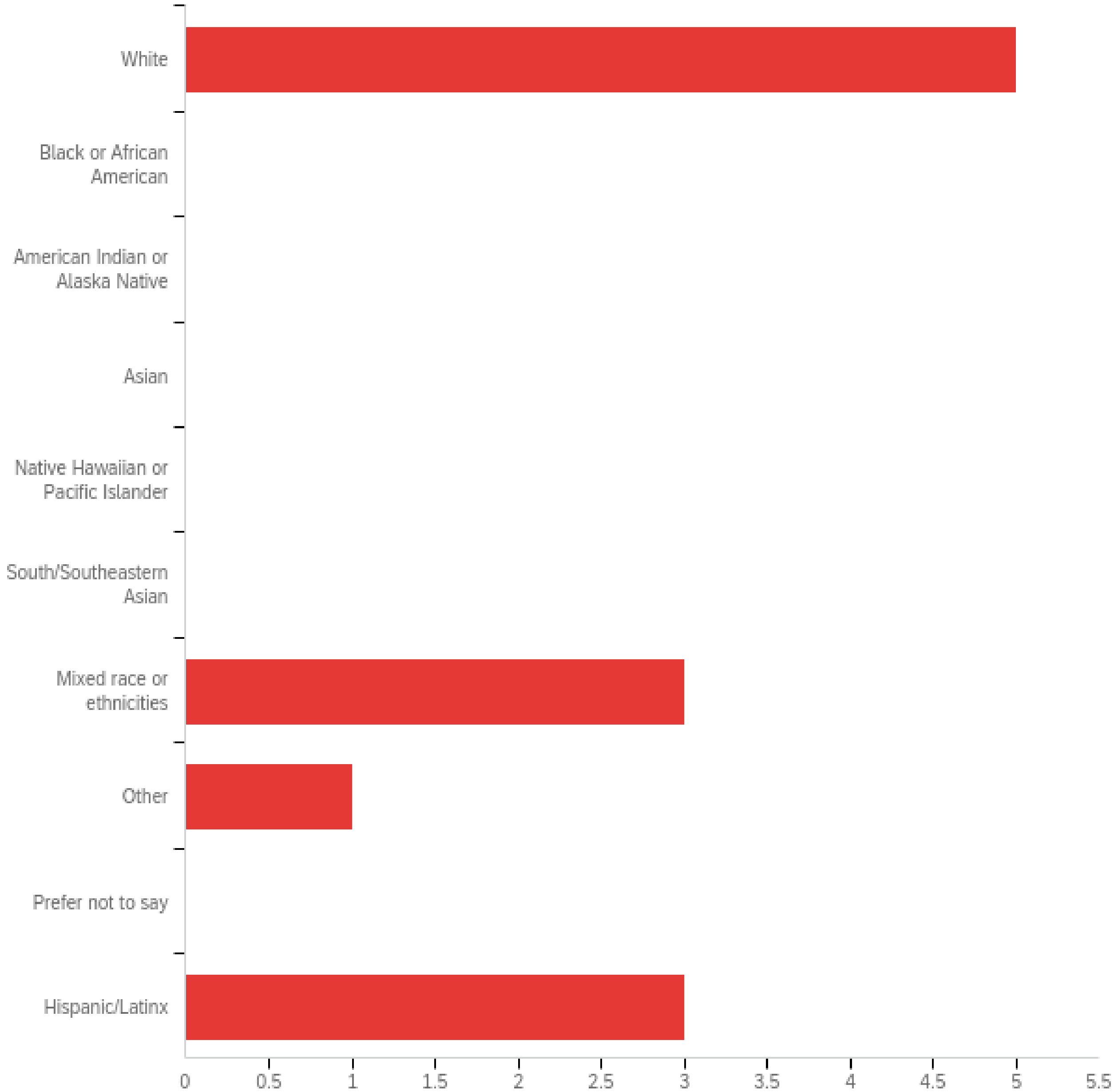
26. What is your gender?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	26. What is your gender?	1.00	2.00	1.42	0.49	0.24	12

#	Answer	%	Count
1	Male	58.33%	7
2	Female	41.67%	5
3	Prefer not to say	0.00%	0
	Total	100%	12

27. What is your race/ethnicity?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	27. What is your race/ethnicity?	1.00	10.00	5.33	3.82	14.56	12

#	Answer	%	Count
1	White	41.67%	5
2	Black or African American	0.00%	0
3	American Indian or Alaska Native	0.00%	0
4	Asian	0.00%	0
5	Native Hawaiian or Pacific Islander	0.00%	0
6	South/Southeastern Asian	0.00%	0
7	Mixed race or ethnicities	25.00%	3
8	Other	8.33%	1
9	Prefer not to say	0.00%	0
10	Hispanic/Latinx	25.00%	3
	Total	100%	12

28. OPTIONAL : Is there anything else you would like to share about your thoughts about any of the following: A. your purpose in life and/or values; B. your experiences doing an engineering project-based service-learning project; and/or C. your future career interests?

28. OPTIONAL : Is there anything else you would like to share about your thoughts about any of the following: A. your purpose in life and/or values; B. your experiences doing an engineering project-based service-learning project; and/or C. your future career interests?
My future career interests are being an aeronautical engineer.
I am teetering between careers I want to do. I could stay the same or change in the future. Whatever I am meant to do I will accomplish.
1 race car driver 2 football player 3 engineer
When i was not sure about what i wanted to be in the past but i kind of don`t care what my job is as long its a descent paying job.
B: I liked the project-based service-learning project because it taught me things that i would learn in high school and we made something usable C: When i grow up i want to be an engineer or a zoologist that can work close up with animals
i really like engineering and i really hope to soon become an engineer. i want to become a structural or mechanical engineer because i like cars and to build buildings and roller coasters. also i think i'm very creative and like to design stuff.