How Do Youth Engage in Engineering Literacies?: A Study of Literacy Learning in Middle and High School Engineering design

by

Carolyn Giroux

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Educational Studies)
in the University of Michigan
2019

Doctoral Committee:

- Professor Elizabeth Birr Moje, Chair
- Associate Professor Gina Cervetti
- Associate Professor Chris Quintana
- Professor Volker Sick

Carolyn S. Giroux

csgiroux@umich.edu

ORCID iD: 0000-0002-1274-7692

Dedication

I dedicate this dissertation to the two teachers and their middle and high school students. Thank you for welcoming me into your classroom communities.

Acknowledgements

I learned how to do the work of education research from my advisor and dissertation chair, Elizabeth Moje. I am deeply thankful for her encouragement and generosity. I will always have fond memories of our meetings together— both the excitement of sharing new discoveries and how she guided me when I did not know how to proceed. Thank you, Elizabeth for making this dissertation process an adventure.

I am also grateful to the members of my dissertation committee: Dr. Volker Sick, Dr. Gina Cervetti, and Dr. Chris Quintana. I have grown as a researcher and writer because of their thoughtful feedback and insight into engineering and literacy research.

I would also like to thank the administration, teachers, students, and staff of Manhattan Bridges High School in New York, NY. As a teacher in this bilingual school community, I saw that language and literacy teaching could give students the skills to pursue questions that mattered in their lives and communities. My high school students gave me the questions about language and literacy learning that drew me to graduate school and motivated me to take on this dissertation study.

I am also thankful to friends and family, both near and far, for their support. My cohort members at the School of Education have been an incredible source of support and inspiration. I am also grateful to my community at Knox Presbyterian Church for being my home in Ann Arbor. I am thankful for the support of my parents, Barry and Kathleen Giroux, as well as my brother, Mark Giroux, nephew, Dylan Giroux, and my sister and brother-in-law, Allison and Brian Ring. Thank you as well to my aunt and uncle, Roxane and Jack Denalsky, who hosted me for holidays in Ohio when I could not make it back home, as well as my family who made the journey to visit: my grandmother Wanda Giroux, cousin Sara Alcott, uncle, Jim Pelati, and my aunt, Amy Giroux, who came in spirit.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

Abstract

Motivated by a desire to maintain national competitiveness in mathematics and the sciences, education reformers have advocated for the teaching and learning of engineering K-12. Advocates of engineering education argue that teaching engineering K-12 will result in a more informed public as well as increase the ability of students to acquire the most competitive jobs in STEM fields. Engineering education research and reform agendas have united around the goals of the Next Generation Science Standards (NGSS) in engineering, a policy initiative that sets expectations for engineering learning K-12. However, the NGSS set goals for learning but do not explain how to reach these goals, leaving teachers with little guidance to design and implement units of engineering study. Specifically, the NGSS stress the importance of engaging students in the practices of engineers (such as “asking questions and defining problems,” “designing solutions,” and “engaging in argument from evidence”). Yet, very little research exists that explains how young people develop the ability to engage in these practices throughout the grade span or what kind of knowledge and skills will best support student engagement in these inquiry practices.

This dissertation study adopts the position that reading and writing are tools of inquiry. That is, engineers follow the cultural norms of the field of engineering to read and write to engage in the inquiry practices of their field and that students also should learn these language tools to support their engagement with engineering practices. Operating from this stance, this study sought to understand the engineering reading and writing knowledge, skills, and practices that supported middle and high school students across three classrooms to engage in the engineering design cycle. The study focused on a group of 12 focal students, four from each classroom (one eighth grade science classroom, one high school engineering design classroom, and one high school biomedical engineering classroom) as they worked through engineering design challenges. Data included fieldnotes, transcripts, interviews (general and think-aloud), and artifacts from 36 days of focal observation during the design challenges as well as contextual data (fieldnotes, videos, teacher interviews, and artifacts) from 45 days of instruction before and after design challenges.

Findings showed that students read and wrote across text to create (or attempt to create) an intellectual product—a warrant— for their design solution. They did this by reading across text to collect evidence that the design worked efficiently and met a user need. The findings also showed that students did not always use textual evidence to inform their design choices because they were not aware that text could help them or because they lacked the literacy knowledge and skill to know how to use text to create or improve a design solution. Together, the findings of this study show that attention to disciplinary literacy teaching and learning in engineering design projects can engage students in deep learning of engineering concepts and practices.

Chapter 1 Introduction

Increasing attention to technology and innovation in the early 21st century has led education policy makers to call for the teaching of engineering in U.S schools. And yet, we know little about how young people learn engineering concepts or practices. In particular, we know little about the literacy demands that accompany proficient engineering skill, and even less about how youth read and write to learn concepts and engage in engineering practices. This dissertation study takes up the question of how students engage in engineering literacies through an examination of the literacies at work in three middle and high school engineering classrooms. The study investigates how youth respond to the literacy demands of engineering design challenges, how they make sense of engineering text, and how they use text to engage in engineering inquiry practices.

Why Engineering?

In recent years, policy makers and reformers in education have argued that instituting engineering programs in primary and secondary schools could increase the public's understanding of science and technology and better recruit and prepare future engineers for university and career. This advocacy comes amidst a growing national concern that waning resources and support in government, industry, and education in science, technology, engineering, and mathematics (STEM) may compromise the ability of the United States to compete in a global economy and maintain its role as a leader of innovation in science and technology. A report from the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine argues that K-12 schooling has not prepared students with the skills to succeed in university STEM programs. The report cites data from the National Assessment of Educational Progress (NAEP) noting that less than one-third of fourth and eighth graders in the United States can perform at or above proficiency in mathematics, a fact that has not changed in subsequent years of the assessment (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007; National Center for Education Statistics, 2017). The report also argues that students in the United States are falling behind students in other countries in their understanding of mathematics and science. Currently the United States ranks 40th out of 72 countries in assessments of mathematics and 25th in science (OECD, 2016). In addition to the argument that engineering education can better prepare young people to compete for high-quality jobs in STEM fields, researchers and practitioners of engineering education also stress the merits of engineering education for all students. Students who experience engineering educational opportunities in primary and secondary school have opportunities to become more informed community members—individuals that can engage more fully with an engineered world and even engineer it themselves. Both engineers and informed community members enable the technological innovation that improves quality of life and spurs economic growth (Katehi, Pearson & Feder, 2009; National Academy of Engineering & National Research Council, 2009).

Yet the social and historical forces at work in the US school system present a set of unique challenges to achieve quality engineering education K-12. Unlike other subjects such as math, science, and history, some researchers have argued that engineering lacks an "epistemic foundation" in American schools (Chandler, Fontenot, & Tate, 2011). That is, researchers and practitioners are not agreed upon what the content of engineering is—what it includes given the many branches of engineering and the wide range of information that is considered to be part of the engineering field as a whole. Engineering education researchers have also drawn attention to their lack of shared language, common goals for teaching and learning, and knowledge of the engineering skills and processes to achieve these goals (Brophy, Klein, Portsmore, & Rogers 2008; Chandler, Fontenot, & Tate, 2011). In addition to these challenges, not enough teachers may be qualified to teach engineering (Moye, Jones, & Dugger, 2015; Krause & Roberts, 2006; Yaşar, Baker, Robinson-Kurpius,) and students who enter engineering classrooms may lack foundational knowledge in math and science (National Academy of Engineering & National Research Council, 2009). Furthermore, no best practices exist to provide guidance for supporting students who may struggle to grasp engineering content.

The Next Generation Science Standards in Engineering (NGSS), published in 2013 and adopted by 19 states (National Science Teachers Association, 2014; NGSS Lead States, 2013) is a recent policy initiative focused on one aspect of this larger problem, with the goal to build common goals for K-12 engineering learning. The NGSS include a framework for engineering design teaching and learning at different grade levels as well as goals for engineering in eight engineering practices (e.g., "asking questions and defining problems," and "planning and carrying out investigations"). Yet, the NGSS are standards, or objectives, for what students might achieve across the grade span. The NGSS are not curriculum. They do not give guidance to teachers on how to teach engineering or how students learn engineering.

This reality places an undue burden on engineering teachers. These teachers, working in many cases without a shared understanding of what engineering education *is*, may not have knowledge of how students can learn engineering practices in grade-appropriate ways or how to teach engineering to the diverse range of students found in public schools in the United States. Yet, teachers have been delivering engineering curriculum in K-12 schools for decades. The exact number of students that have taken engineering courses is unknown, but a report by The National Academy of Engineering estimates that several dozen engineering curricula and programs have been implemented in K-12 schools since the 1900s (National Academy of Engineering & National Research Council, 2009). Consequently, in schools around the country engineering teachers may be resorting to trial and error to find what works best for their students without coherent guidance from the research literature to inform their teaching, and “trial and error” teaching is likely not sufficient to support young people to experience deep learning in engineering and realize the aims of the national call for K-12 engineering education.

By “deep learning” I mean learning that immerses students in engineering inquiry in age and grade-appropriate ways, not only learning facts about engineering or engaging in isolated “engineer-like” behaviors (such as building a model from a set). Learning engineering involves engagement with engineering practices, for engineering (or any discipline or field) is “not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge” (National Research Council, 2012, p. 26). Deep learning engages students in taking on the practices of engineers, such as defining problems and designing solutions[1] (NGSS Lead States, 2013) to support students to learn how technology can improve their lives and the lives of others with a degree of sophistication that might not be achievable by memorizing content or engaging in decontextualized behaviors or skills. Furthermore, each practice is a goal-oriented action sustained by knowledge, skills, and habits of mind. To engage in the practices means leaning the skills and tools that support

---

[1] [1] The NGSS include a list of eight practices for science and engineering. I also refer to the three component parts of the design cycle, which the NGSS call “component ideas” as practices because they define three ways to engage in the design cycle.

engagement. So what are the academic tools that a student would need to support them to delimit an engineering problem, or to design and optimize a solution?

Why Engineering Literacy?

This dissertation study takes the position that reading and writing— the literacy practices of engineering— are tools that support engagement in engineering practice. The work of engineering does not solely consist of manipulating materials; engineers read and write to engage in the inquiry practices of their field (Moje, 2015). As in science, engineers "use texts to generate new research questions and to provide the background necessary for research design and investigation" (Pearson, Moje, & Greanleaf, 2010, p.328). Although a person might walk into a laboratory and not immediately notice scientists working with text, scientists could not carry out the work of science as it is known today without text or references to text (Norris & Phillips, 2003) and the same holds true of engineers working in engineering laboratories and industry settings (Giroux & Moje, 2017; Tenopir & King, 2004). Yet, very little is known about how professional engineers work with specific texts, and much less is known about how young people in K-12 classrooms read and write engineering text.

Furthermore, the way an engineer engages with a text (such as a record of documentation) is different from the way a historian works with a primary source document or the way a scientist works with a lab report (Moje, 2015; Shanahan & Shanahan, 2008; Wineburg, 1991, 1998). Each disciplinary professional attends to different information as they read and draws different kinds of interpretations from text (Rainey, 2017; Wineburg, 1991, 1998). They navigate a different lexicon of disciplinary language and follow different norms for conveying information in writing (Dym, Agogino, Eris, Frey, & Leifer, 2005). What counts as evidence changes from one discipline to the next, as well as ways that disciplinary professionals gather and present evidence (Toulmin, 2003). Therefore, a student with the ability to decode the words in a text may be able to glean some knowledge from reading a text in an engineering classroom, but only insiders who are familiar with the ways engineers read and write will be able to use a text as an engineer would, to read and write to engage in engineering inquiry practices. Today, engineering teachers working in classrooms will likely engage students in working with text in some way, but what types of reading and writing, exactly, will support students to think as engineers and to engage in the engineering practices? Very little research exists that explains how school-aged children develop engineering practices and there is even less research into the literacy engagement that supports these practices. Yet if students in engineering classrooms are to learn the literacy tools that sustain deep learning in engineering classrooms, researchers and practitioners need first to understand what these literacy tools are and how young people engage with these literacy tools to participate in engineering practices in K-12 engineering classrooms.

Study Overview: Research Questions and Research Design

This study examines the reading and writing opportunities that are afforded middle and high school students as they work through engineering design challenges and seeks to characterize youth literacy engagement during these opportunities as students delimit engineering problems and develop and optimize engineering solutions. I posed the following research questions:

1. How do students engage in literacy practice as they work toward an engineering design solution (or, inside of an engineering design project/challenge)?
2. What opportunities do middle and high school students have to learn literacy skills, knowledge, and practices in engineering design classrooms? How does literacy engagement appear to be influenced by the instructional context?

The study examined several aspects of youth engagement with engineering texts, by focusing on a group of twelve focal students (four from each class) as they completed engineering design projects. Focal data included videos, transcripts of small group interaction, interviews with focal students (general and think-aloud), fieldnotes and artifacts (documents and samples of student work) taken from the days of the engineering design challenge. Contextual data included interviews with teachers, videos, fieldnotes, and artifacts from the days before and after the design challenges.

Organization of the Dissertation

In Chapter 2, I present the conceptual framework for this study. I start with a discussion of literacy learning and teaching, focusing on the nature and goals of disciplinary literacy teaching and learning. Then I present a summary of research on the reading and writing of professional engineers from several related disciplines and conclude with an argument for studying literacy teaching and learning in middle and high school classrooms. In Chapter 3, I describe the design of the study and present the research context and participants. In Chapters 4 through 6, I present my findings organized around patterns in student literacy engagement: how students engaged with “new” engineering texts that were less common to other subject areas (Chapter 4), how students engaged with familiar classroom texts such as articles (Chapter 5) and how students engaged with multiple texts to warrant their design solution (Chapter 6). In Chapter 7 I discuss the findings from Chapters 4 through 6 and draw implications from these findings for research, policy, and practice.

Chapter 2 : Theoretical and Empirical Perspectives

In Chapter 1, I argued that reading and writing support and mediate the knowledge-generating and knowledge-sharing practices of each discipline or field including the field of engineering. I continue this argument in this chapter in more detail through a review of theoretical and empirical research. First, I review literature in literacy research to examine the ways that reading and writing are culturally and socially situated and aligned to the inquiry practices of each discipline and field. Second, I examine the literate practice of the field of engineering, drawing on research from several related bodies of research (including composition, science and technology studies, linguistics, and communication studies) to present an account of reading and writing of professional engineers. I contrast this section with the third section of the chapter, a review of studies of K-12 engineering reading and writing, to explain that much more is known about how professional engineers read and write than how young people read and write as they are engaged in engineering activity in K-12 classrooms. I conclude this chapter with an argument for more research in K-12 engineering literacy, explaining specifically the contribution this dissertation study aims to make to disciplinary literacy research in engineering.

Section 1: Reading and Writing are Tools that Support Inquiry in the Disciplines

The theory that frames this dissertation study is that reading and writing are social practices (Gee, 2015; Heath, 1983; Street, 1984). Gee (2015) argued that groups of people have Discourses, or “identity kits,” ways of speaking, reading, and writing, but also ways of presenting themselves, interacting, and communicating that identify them as members in a particular group. Gee called these ways of being and communicating “saying(writing)-doing-being-valuing-believing combinations," to explain that the qualities that make cultural groups "hang together" include language and literate practice in addition to the beliefs, values, and norms that are markers of cultural identity. People interact with several different cultural groups in their daily lives such as religious groups, racial and ethnic groups, and companies and organizations, and how a person communicates changes according to the values, norms, and beliefs of each group. For example, a person would not communicate with community members in a religious service in the same way that he or she would communicate with colleagues in a meeting at work.

Of particular interest to this dissertation study are the language and literacy demands that students face in schools and how students approach and engage with literacy practices in the academic disciplines and fields. Heath used the term "ways with words" (Heath, 1983) to express the role that language and literacy play in the cultures that children encounter in their daily lives (in both home culture and school culture), arguing that each child is socialized into culturally-specific ways of speaking, reading, and writing each governed by cultural norms and beliefs. Heath's (1983) study of children in three communities found differences in the "ways with words" in the homes of one black working-class neighborhood and one white working-class neighborhood and the "ways with words" that were valued in the school that was governed by middle-class townspeople. For example, students from the black working-class community were socialized through participation in religious services to believe that they should not extend or interpret the written word in public. These same children avoided answering interpretive questions at school, causing some teachers to believe "some of them [students from the black working-class community] have a hearing problem; it is as though they don't hear me ask a question" (Heath, 1983, p., 269). In high school, Heath characterized these same children as disconnected with the school system, waiting for school to end or to reach the age where they could choose to drop out of school (p.349). Heath's work argued not only that differences existed in literate practice among the working-class homes and middle-class school culture, but also that these differences in "ways with words" accounted for some of the difference in educational outcomes of working-class children compared to middle-class children in the neighborhoods she studied.

Many other research agendas have examined aspects of the "ways with words" of schools and academia, showing the difference between academic language and everyday language (Schleppegrell, 2004; Snow & Ucelli, 2009), and highlighting features of academic communication including participation structures (Au, 1980; Philips, 1972) and forms of discourse (Gutiérrez, 1995; Lee, 1995). But the school, although in many cases governed by middle-class cultural values, is not one homogenous culture. Many home cultures are represented among the student population, and students also navigate many disciplinary cultures over the course of a single school day (Alvermann & Moje, 2013). To understand the way that students navigate between home and school literacies, it is necessary to understand the specific characteristics of the disciplinary cultures that students encounter during the school day.

The academic disciplines are cultures (Moje, 2015; Street, 1984) each with their own "ways with words" as well as beliefs, values, and norms that influence reading, writing, and communication (Moje, 2008; Moje, 2015; Shanahan & Shanahan, 2008). This means that in school a student relies on knowledge of the cultural practices of a discipline to both comprehend and produce academic text:

> Moving from one subject area to the next, they [students] must tap into entirely different sets of vocabulary and background knowledge. They [students] must learn to write well

> in many genres, as well as realize that chemists, historians, mathematicians, journalists, and members of every other profession have their own unique ways of sharing information, getting people's attention, debating, responding to criticism, reporting facts, and establishing authority (Heller & Greenleaf, 2007, p. 7)

Without understanding the ways that members of a particular discipline read and write as well as the norms and values that affect this communication, students may not write or interpret text in a way that "holds weight" with members of a particular discipline—in a way that communicates in the same Discourses and leveraging the same "ways with words."

This is not to say that every process involved in comprehending a text varies from one social context to the next but rather that the context in which a text is read influences the interpretation that a reader draws from a text. Within the field of literacy research, researchers conceive of reading comprehension as an interaction between a reader, a text, and an activity situated within a particular social context (Kintsch, 1998; Moje, Dillon, & O'Brien, 2000; Rosenblatt, 1994; Snow & Sweet, 2002). A text does not hold one "correct" objective meaning but meaning is constructed by the reader applying their background knowledge and experience in interaction with the content, organizational features, and purposes of a particular text (Rosenblatt, 1994). In constructing meaning of a text, a reader's (or writer's) meaning-making is influenced by the purposes and values of the author of the text (or the intended reader), the goals of a particular activity, and the cultural context. Therefore, a reader might utilize general processes such as decoding and word-recognition skills to build knowledge of words and progressively develop a coherent understanding of words, clauses, sentences and paragraphs of text. However, to go beyond a shallow understanding of the explicit meaning of a text (gleaned from the text alone), a reader must integrate relevant prior knowledge and knowledge of the social context to make an interpretation (Kintsch 1998). For students to construct interpretations that "count" in a particular discipline means students must be able to integrate cultural knowledge about the discipline (including their Discourses and "ways with words") as they work with text.

Disciplinary literacy research argues that students learn to engage in the inquiry practices of the disciplines as they read and write to engage with text following the norms, values, and conventions of the disciplines (Moje, 2008; Moje, 2015; Shanahan & Shanahan, 2008). These researchers argue that attention to disciplinary ways of reading and writing in primary and secondary schools may create a generation of more proficient readers and writers (Lee & Spratley, 2010). However, the goals of disciplinary literacy teaching and learning go beyond college and career preparation, or the approximation of professional ways of reading and writing. Engaging in literacy practice that supports disciplinary inquiry allows students insight into the ways that knowledge is generated and produced and gives students the tools to critique its production, which researchers argue is "where power in the discipline lies.. some of the power of knowledge comes from being an active part if its production rather than from merely possessing it" (Moje, 2007, p. 8). The ability to critique knowledge production is a useful skill for all informed community members: a student of history, for example, could develop the ability to critically examine the evidence behind a news story (or "fake news" story), a student of science could develop the ability to investigate the research for and against climate change, and a student of engineering could develop the ability to more thoughtfully interact with engineered products and even engineer their own solutions in their homes and communities. Students learn the "ways with words" to read and write to participate in disciplinary inquiry. In turn, engagement with these disciplinary ways of reading and writing supports students to understand the process of inquiry as well as learn the knowledge that results from this process.

Research in the disciplinary literacy practices of professionals provides some specific examples of the “ways with words” that support disciplinary inquiry practice, and these examples of “ways with words” highlight the ways that reading and writing practice differs among the disciplines and fields. Some general practices of inquiry occur in all disciplines. All disciplines frame problems or pose questions about the world, work with data in some way, and communicate and examine claims drawn from this data (Moje, 2015). Yet, the way that professionals engage in these inquiry practices varies among the disciplines, and so do the reading and writing that support engagement in inquiry. For example, one study of two chemists, two historians, and two mathematicians (Shanahan, Shanahan, & Misischia, 2012) found differences in the way that the disciplinary professionals read, evaluated, and responded to text. For example, the historians considered the context of the document they were reading to understand what the authors of the document knew at the time while mathematicians did not report using any information about the context of the document in their interpretations. Historians critiqued text by investigating the stance of the author while chemists critiqued the text by weighing the scientific information against other scientific evidence.

Wineburg’s (1991) study of historians and history students working with primary source documents found that historians “seemed to view texts not as vehicles but as people, not as bits of information to be gathered but as social exchanges to be understood” (p. 83). Historians read primary source documents by sourcing the text—determining its origin and author, the historical context, and the worldview of an author that led to their interpretation of this context. Historians created “elaborate scenarios” (p. 8) about how a certain document came to be. Historians believed each source to be biased and sought to understand how that bias influenced the text, while students of history attributed bias to some documents and not to others. Wineburg argued that historians created a “representation of the subtext,” that they built an understanding of an author’s worldview that they used to interpret a historical text (Wineburg, 1999). Wineburg also argued that historians built an “event model,” building an understanding of the details of a particular historical event by reading across historical text, integrating textual information as well as their own knowledge and beliefs (Wineburg, 1991). Similarly, Rainey’s (2017) study examined the interpretive processes of literary scholars (professors and doctoral candidates). Findings from this study show that readers constructed “interpretive puzzles,” questions designed to have many possible answers that allowed readers to take multiple perspectives of the text. The literary scholars worked through these puzzles drawing on their knowledge of the field of literary studies and the work of literary critics past and present, looking for puzzles to draw out new narratives and spark debate.

This research into the literacy practices of disciplinary professionals provides examples of reading and writing that is culturally situated, that supports engagement in the particular inquiry practices of each academic discipline. In the next section I draw from research across several related disciplines and fields (literacy studies, composition, science and technology studies, linguistics, and communication studies) looking on studies that directly and indirectly examine the reading and writing practices of engineers. Although much more research is needed to understand the literate practice of engineers (especially their interpretive processes), this research can explain some of the ways that reading and writing support engineers to carry out their work and shed light on the social nature of engineer reading and writing as well as the shared norms and beliefs that influence reading and writing.

Section 2: The Reading and Writing of Professional Engineers

Norris and Phillips (2003) discuss the relationship between literacy and the disciplines of science as a constitutive relationship. “Remove a constituent, and the whole goes with it. Throw away the cover and keep the contents, and you still have a book; throw away the contents and keep the cover, and you no longer have a book” (Norris & Phillips, 2003, p. 226)**.** In the same way, reading and writing are not additions to the work of engineering. Several decades of research in science and technology studies, communication studies, composition research, and linguistics begin to explain the constitutive relationship between reading and writing and the work of professional engineers. In this section I review research to argue that

- engineers have shared beliefs about reading and writing
- engineers have shared purposes for reading and writing
- engineers read and write multiple text types
- engineers possess shared language, and
- engineers write collaboratively for multiple audiences.

Shared values and beliefs about writing. Surveys of practicing engineers (Jenkins, Jordan, & Weiland, 1993; Tenopir & King, 2004; Yore, Hand, & Florence, 2004) presented evidence that engineers have culturally-defined standards for writing. In these surveys, engineers agreed on what makes their writing particularly “good quality”: writing with a logical presentation of ideas supported with claims from research. Yore, Hand, and Florence’s (2004) analysis of questionnaires and interviews of scientists and engineers explored the way that engineers understood writing in their work. Engineers (as well as scientists) described good writing as clear and following a logical flow of information. Similarly, professional engineers in Jenkins, Jordan & Weiland’s (1993) study reported that good writing should present ideas logically, clearly state a problem, support claims with research, and draw valid conclusions from research.

These surveys also reported that engineers spent a large amount of their time reading and writing. Tenopir and King's (2004) review of surveys and interviews in engineering communication found that engineers reported that communication took up to 75% of their time. This survey research cannot tell us exactly what distinguishes "good" evidence from bad or exactly what engineers mean when they say writing must be "logical," but this work shows that engineers spent much of their time reading and writing and that they agreed on a broad definition of writing quality.

Shared purposes for reading and writing: To understand how technology works and solve engineering problems. Findings from surveys of engineers (Jenkins, Jordan, & Weiland, 1993; Tenopir & King, 2004; Yore, Hand, & Florence, 2004) also found themes in the way that engineers described their work. Engineers saw their work as problem-solving and understood themselves to be reading and writing in order to make their work useful to others.

Although these surveys provided information about how engineers describe their work, complementary research in science and technology studies has used observation to document the work that happened inside of the laboratory. Lab ethnographies (Knorr-Cetina, 1981; Latour & Woolgar, 1979; Lynch, 1985) described how scientists worked with lab equipment to understand the natural world. Scientists in these lab ethnographies used lab equipment to create texts that represented phenomena in the natural world, through a process of "inscription" (Latour & Wolgar, 1979), a process of constructing facts that explained real-world phenomena through the reading and writing of text. Latour and Wolgar (1979) referred to scientists as "a tribe of readers and writers who spend two-thirds of their time working with large inscription devices" (p.69), with publication as their "main objective" (p.71). These researchers examined how lab equipment had the ability to change the nature of what was observed, from "a material substance into a figure or diagram" (p.51). Similarly, Lynch (1985) brought attention to how reading and writing changed the way that researchers viewed the natural world. He called attention to translation artifacts, or "troubles" (p. 84), such as blurriness, optical abrasions, and other consequences that came from using lab equipment to construct texts. These artifacts were the inevitable result of viewing the natural world through technology.

More modern ethnographies of engineering laboratories provided evidence that inscription is also an element of engineer work, such as Suchman's (2011) analysis of a civil engineer working with computer software and images taken of a construction site. To solve problems in civil engineering such as how much dirt to remove to build a highway, one engineer worked with images, measurement software, and Computer Aided Design (CAD), several steps removed from the site of construction. Taken together, ethnographic observation of science and engineering laboratories showed how scientists read and wrote to understand the natural world, and how engineers might also do the same but for the purposes of solving an engineering problem.

My own (2019) ethnographic study of the lab work of 11 research engineers' over a six-month period also argued that problem-solving with technology was the goal of engineer reading and writing in the offices and test cells of one engineering laboratory. Engineers in this laboratory also read and wrote to understand how technology operated in real-world conditions and applied this knowledge to bring about technological innovation. My work specified three ways that the 11 engineers read and wrote to achieve this purpose. First, the engineers read and wrote to create the most informed experimental design, to "make it work" in uncertain conditions with a unique experimental setup. This “reading and writing to make it work” occurred in the planning and prototyping phases of experimental design but continued throughout an experiment when the equipment did not work as expected. Second, the engineers read and wrote the machines of their experimental setup, inputting information and reading output from a variety of interconnected machines with different modes and systems of input and output. The engineers’ belief that they had collected “good data” relied on their ability to maintain a well-functioning experimental setup through reading and writing. Finally, the 11 engineers read and wrote throughout an experiment to manage an experiment—to document what happened and provide an explanation of the results. The engineers could not know what they would find in a given the experiment and could not thoroughly document all aspects of their study. As a result, they used reading and writing to keep track of experiments through multiple systems of documentation in projects that could take several years to complete.

Engineers read and write multiple text types. Ethnographic research in scientific laboratories argued that published papers were important, even the main goal, of laboratory work (Knorr-Cetina, 1981; Latour & Woolger, 1979). Latour and Woolgar (1979) questioned the veracity of “facts” represented in published papers, because they were constructed through the process of inscription and were separate from the reality of the natural world. Knorr-Cetina’s (1981) work discussed the structure and language of published papers in more detail, noting the neutral language and passive tone of scientific writing, arguing that writing constrained the construction of knowledge because the iterative inter-connected nature of the work in the lab had to adapt to the rigid organization required in report writing. In addition to published papers, lab ethnographies documented a wide range of text (Latour & Woolgar, 1979; Knorr-Cetina, 1981; Lynch, 1985), from notes and labels to scientific articles and reports and the output of various lab equipment. A variety of texts were also present in these accounts— including images, print text, digital text, graphs, and sketches.

In addition, Tenopir and King's (2004) review of communication research documented the many text types that engineers used in their communication, showing that engineers communicated orally (in meetings and informal discussions) and through printed text (articles, books and patents). Each of these channels had multiple text types. Engineers also searched for information from many sources within the lab: lab colleagues and technical staff, previous company research, experimentation, work from other divisions of the same company, and vendors and suppliers.

Engineers possess specialized language. A review of research in design thinking (Dym et al., 2005) discussed the "language of design thinking" including specialized vocabulary to describe a design and communicate this idea to design teams and manufacturers. Similarly, linguistic analyses of engineering text showed how engineers leverage certain linguistic resources to communicate. Koutsantoni (2006)'s analysis of professional research articles and student theses showed that engineer writers used linguistic resources to hedge (qualify or soften the impact of) claims about their work. Also, students hedged more and were less likely to take any responsibility for the outcomes presented in their work. Koutsantoni's work drew attention to the function of hedging and its importance in explaining, presenting evidence, and drawing conclusions in reports of engineering projects. The work also showed how language use develops over time, as professionals hedged in their writing but not in a way that absolved them of any responsibility for their work.

McKenna's (1997) linguistic analysis of three engineer reports showed how engineers used unmarked themes to explain real-world processes and phenomena using hypothetical objectives. For example, in the sentence, "The alarm sensors operate on a thermal mapping principle" (p.201), the authors employed an unmarked theme ("the alarm sensors"), and a hypothetical, decontextualized phenomena (the alarm going off if there is a fire) to focus on a scientific principle ("thermal mapping"). This use of unmarked themes showed the way that engineers used language resources to explain engineering processes, suggesting that engineers draw on language resources in ways that are specific to communication in their field. Taken together, this research in communication and linguistics (Dym et al., 2005; Koutsantoni, 2006; McKenna, 1997) explained just a small portion of the language of engineering, yet the work showed the ways that engineers used language in precise ways.

Multiple authors, multiple audiences. In the field of composition research, studies of individual engineers and engineers working in small groups explained some of the qualities of the reading and writing that make up an engineer's work. The research shows that engineer writing can be collaborative and that engineers write using different text types for many different audiences. Studies of individual writing also explain how engineers generate ideas through writing.

Three studies of engineer writing found that engineers wrote collaboratively (Pogner, 2003; Selzer, 1983; Winsor, 1989). In one study (Pogner, 2003), engineers participated in cycles of writing, feedback, and revision that were taken on by team members with different areas of expertise. As their writing evolved, so did the ideas being negotiated by the engineer team, eventually resulting in a list of solutions. Collaborative writing may afford opportunities for growth and reflection, although there are certain written tasks where engineers may follow a more linear writing process and spend less time in revision (Selzer, 1983).

Windsor's (1989) study of the report writing of one group of engineers focused on the kind of ideas generated through individual and collaborative writing and found that engineers write to disseminate existing knowledge as well as to generate new ideas. When writing a collaborative report for a conference, the engineer who led the report writing did not generate any new ideas. Windsor showed that the nature and meaning of the technology he was writing about had already been "inscribed" (Latour & Woolger, 1979) by other texts within the company that discussed the same technology. The engineer's writing was constrained to formulaic repeating of language and ideas previously represented in other company texts. This differed from another collaborative document, the progress report. The engineer who led the progress report writing did generate new ideas because he was writing about new technology. Windsor characterizes the writing of this progress report as a negation, an attempt to inscribe meaning concerning technologies where there was little or no existing company literature. This study shows that to complete different reports, a team of engineers had write differently based on the number of company publications on the same technology that existed, and that engineers wrote for the purposes of conveying knowledge in formulaic ways but also wrote in more creative ways to negotiate the meaning of new technologies.

Brown's (1994) case study of one 12-page collaborative report, found that engineers wrote for several audiences: policy makers, project managers at the funding organization, outside industry reviewers, internal managers, and the public. Even though the report was primarily for policymakers, the writers were also very concerned about the reactions of outside industry reviewers. Engineers had to understand the positions of many different stakeholders to write a successful report and balance the needs of each of these audiences as they were writing. In Winsor's (1999) study, engineers documented for several audiences and were primarily concerned to document for company management. The four engineers in this study reported that after leaving university the engineers began to use documentation to prove that they had done their job and avoid any potential disciplinary procedures from their employer in the event that something went wrong. A trail of documentation could protect the engineer from losing their job in the event that a colleague failed to complete their work. As the engineers learned to write for many audiences, they were also able to write more effectively—to use writing to ensure job security.

Taken together, these studies of engineer writing argue that engineer writers engage in reading and writing various genres of text and write for several different audiences at once. Writing that seems simple at first glance (such as documentation) may be more complex and may require a more nuanced understanding of audience and purpose.

Engineer literacies: Conclusion. An analysis of communication research, composition research, linguistic analysis, and literacy research show that engineers engage in a set of specialized language and literacy practices that are utilized for effective communication within the field of engineering. The reading and writing of engineers is different from that of scientists and mathematicians. Engineers use their time and resources differently (Tenopir & King, 2004), and describe their work in different ways than scientists (Yore, Hand, & Florence, 2004). Engineer reading and writing is aimed at a complex network of audiences (Brown, 1994; Tenopir & King, 2004; Windsor, 1999) and leverages specific language resources (Koutsantoni, 2006, McKenna, 1997). Engineers read and write a variety of multimodal texts (Brown, 1994; Pogner, 2003; Selzer, 1983; Tenopir & King, 2004; Winsor, 1989; Winsor, 1999). Finally, the purpose of engineer reading and writing across these studies was to solve problems with technology at work in the natural world (Giroux & Moje, 2017; Suchman, 2011; Yore, Hand, & Florence, 2004).

These language and literacy practices support and mediate the work of professional engineers and it follows that youth in K-12 engineering classrooms should read and write in similar ways to support their engineering work. However, very few studies have investigated youth literacy engagement in K-12 engineering classrooms. In the next section, I will review these studies and then conclude this chapter with a call for more research in youth engineering literacy.

Section 3: Disciplinary Literacy Teaching and Learning in Engineering

The aim of teaching and learning disciplinary literacy is to provide authentic reading and writing experiences in the K-12 classroom where students learn the literacy skills and knowledge to engage in the practices of engineers. Yet, much of the existing engineering education curricula does not directly attend to reading and writing instruction. Engineering curricula employ a wide variety of text. For example, some curricula include nonfiction text (e.g., SAE International, 2017), while others add fiction text to engineering units to explain human problems (e.g., Cunningham, 2009). Some curricula engage students in programming robots using computer software (e.g., Cejka, Rogers, & Portsmore, 2006) or focus their curriculum around machines such as a sensor (Rogers & Portsmore, 2004), electron microscope (Chumbley, Hargrave, Constant & Hand, 2002), or electrocardiogram (Klein & Sherwood, 2005). In these engineering curricula, students read and write to participate in class but do not always receive instruction in how to read and write as engineers. In contrast to these curricula, I found three studies of disciplinary literacy teaching and learning in K-12 engineering classes (McVee, Silvestri, Shanahan & English, 2017; Wilson-Lopez & Minichiello, 2017; Wilson, Smith, & Householder, 2014). These three studies investigate the nature of youth engineering literacy engagement and explain how this engagement supports students to engage in engineering inquiry practices.

Wilson, Smith, & Householder's (2014) study followed two groups of 17-year olds as they engaged in two engineering design challenges. The design projects had real clients, an engineer from Engineers Without Borders seeking wheelchair designs, and an engineer from a local Assistive Technology Lab who wanted to improve the design of an assistive device for a man with muscular dystrophy. The study found that aspects of students' literacy practice supported students to participate in engineering design challenges. Students showed that they could annotate a problem statement, search the internet for design information, and present a design solution. Youth also read problem statements to plan and prioritize their work and read to identify gaps in available information. The study also found that students faced literacy challenges during the design activity. Students had trouble comprehending problem statements and forgot to document (and therefore remember) design elements and criteria.

Wilson-Lopez and Minichiello (2017) examine youth literacy engagement during an engineering design project titled the "Parking Lot Challenge." In the "Parking Lot Challenge," seventh-grade students decided on the idea to improve a dangerous parking lot in their school, They constrained their design to fit regulations of local regulatory agencies and the school board and presented their work to the school board during a public meeting. During the challenge, teachers used examples of engineering text, such as a parking lot design made by a civil engineer, to teach students disciplinary ways of communicating ideas. Other texts from the "Parking Lot Challenge" included transcripts from interviews with parents, students, and community members; aerial photographs data displays with statistical information (e.g., the risk of getting hit by a car); regulations for parking lots (simplified); estimates (e.g., for installation of a stop sign); and lists and tables of proposed design solutions. Findings showed that students read and wrote to engage in two engineering practices: testing and optimizing solutions and communicating solutions. To test and optimize solutions, students developed spreadsheets that predicted the cost of a parking lot with different elements such as a stop sign or crosswalk. To communicate solutions, students created PowerPoint solutions to argue for their parking lot design (in comparison with four designs proposed by a civil engineer).

Silvestri, Shanahan & McVee (2017) examine third grade ELL students' reading and writing of engineering design journals in an after-school engineering design program. Students wrote, sketched, and took notes in their digital journals and discussed their ideas in small groups using voice, gesture, movement, and translations. Findings showed that the journals gave students an opportunity to engage in multimodal communication as engineers would. At the same time, the journals afforded students multiple "entry points" to share their design ideas and give feedback to other students on their design ideas. The students also used the journals to access resources in their first language as they researched and documented their design ideas.

These studies highlight the possibilities of disciplinary literacy teaching and learning in engineering to support students in meaningful engineering inquiry. However, all three studies examine youth literacy engagement during implementation of curriculum that they had designed. I could not find any studies of youth literacy engagement that examine the opportunities afforded to students in K-12 classrooms led by a single engineering teacher. As partnerships between engineering teachers and literacy researchers are rare, it is worth studying how students read and write in more common instructional contexts, with one engineering teacher that is responsible for designing and teaching their own curriculum (or adapting an existing curriculum for a specific group of students). Additionally, only one study (Lopez & Minichiello, 2017) focused on literacy learning in an engineering course (as opposed to an after-school program). More research is needed to understand youth literacy engagement in K-12 and across K-12 school settings (in multiple schools, among students of different grade levels), especially research that can observe students over more than one engineering design challenge.

Conclusion: The Need to Study Disciplinary Literacy Learning in Middle and High School

The research on engineering literacies presented in this review shows that although engineers have developed ways of reading and writing to communicate in their field and that the process of becoming an engineer includes apprenticeship into these specialized ways of communication, young people do not have many opportunities in K-12 classrooms to engage with engineering reading and writing. Apart from three studies of K-12 engineering literacy teaching, there were very few (possibly no) studies that examined literacy teaching and learning in K-12 engineering classrooms. Furthermore, only two of these three studies of K-12 engineering literacy took place inside engineering classrooms and none of this research studied literacy engagement over more than one unit of study. One reason why some K-12 engineering education research does not attend to reading and writing might be because so little is known about how young people read and write engineering texts and how reading and writing influences their engineering work. For an apprenticeship model of instruction to succeed, more research is needed to understand what youth bring to engineering classrooms and how they engage in and learn new literacy practices in the course of their experience. This dissertation study has the potential to add to the existing literature by studying youth engagement with engineering literacy inside of middle and high school classrooms. The goal of this study is to understand how youth read and write in some of the few classrooms in the country where engineering teachers are engaging students in disciplinary literacy to prepare students for college and career.

Chapter 3 Research Design and Methods

This multi-site case study examined the literacy practices of middle and high school students at three schools as they engaged in engineering design projects. My focus was on the opportunities that young people had to read and write during engineering design challenges together with an analysis of how students engaged in literate practice during these opportunities. I also collected data on the instruction that teachers provided, using the instructional data to understand the instructional context of literacy engagement. Thus, the focus of my investigation was on students and their literacy practice and learning; instructional data were collected only for the purposes of understanding the context in which those practices and learning took place.

Research Questions

My research questions were as follows:

1. How do students engage in literacy practice as they work toward an engineering design solution (or, inside of an engineering design project/challenge)?
2. What opportunities do middle and high school students have to learn literacy skills, knowledge, and practices in engineering design classrooms? How does literacy engagement appear to be influenced by the instructional context?

I designed these questions to understand the engineering literacy practices of three classrooms with a focus on individual students who demonstrate their literacy practice through specialized ways of reading and writing as they engage in engineering design projects. These questions did not capture all the ways students read and wrote in the classroom, nor did they present a comprehensive analysis of all forms of literacy engagement within engineering design projects, as I only observed a total of five design projects across the three classrooms. I designed these questions to surface the literacies that students enacted in a particular instructional context. The questions were not able to uncover the complete range of literacies in each student's repertoire. Instead, these questions allowed me to look at instances of engagement with the engineering design process to document and describe the elements of literacy practice that supported students to engage in engineering thinking and engineering practices.

Guided by these questions, my findings have the potential to contribute to the field of literacy research and engineering education research, providing an understanding of how young people in three middle and high school classrooms engage in reading and writing to support engineering inquiry. Although researchers have studied the ways that professionals enact disciplinary literacies in engineering, there is very little research on how youth learn and enact disciplinary literacies in classroom engineering projects. Furthermore, engagement in engineering inquiry practice is the goal of the Next Generation Science Standards but very little research exists that examines how students learn engineering practices across the grade span and even less research seeks to understand the reading and writing that supports engagement in these engineering practices. This study has the potential to explain in a small number of cases how engagement with the reading and writing of engineering text supports student engagement in engineering inquiry and fosters deep learning in engineering design projects.

Study Overview

This study of youth engineering literacy examined several aspects of youth engagement with engineering texts during the engineering design projects contained in three middle and high school engineering courses. The study focused on a group of twelve focal students (one focal group of four students from each engineering course) and followed each group of focal students over the course of several weeks of instruction. In the eighth grade science course, I observed the focal group for 20 class periods. In the high school engineering design classroom, I observed the focal group for 36 class periods. In the high school biomedical engineering classroom, I observed the focal group for 25 class periods. (See Table 1.) The study used semi-structured interviews, observation, and think-aloud interviews, to explain how and why students read and wrote as they were engaged in designing an engineering solution.

Table 1 presents an overview of the amount of time spent in each classroom and on each engineering design project. I observed in each classroom for several full periods of instruction before and after an engineering design challenge but the focal data for the study came from the periods in which students were engaged in an engineering design challenge. In addition to collecting transcripts of the focal group work and videos of the full classroom, I also informally interviewed the focal students *in situ*, prompting them to explain what they were doing and why as they worked through an engineering design challenge. To uncover any differences in the way students were comprehending and interpreting text, I conducted think-aloud interviews with two texts used during the engineering design projects before and after the engineering design challenges in each course. These think-aloud texts were an article and a data table (in the eighth grade science class), an article abstract and a graph (in the high school biomedical engineering class) and a design brief and a CAD drawing (in the high school engineering design class).

These data did not allow me to study the full scope of what youth learned in engineering design courses because I only collected data in each classroom for one or two units of study. However, I was able to collect data that allowed me to analyze student approaches to engineering literacies, their engagement with literacy during a sequence of engineering design projects, and what they knew and could do after one or two units of study. In what follows, I provide more detail on research contexts, participants, and method of data collection and analysis.

Table 1. Days of Observation Across Three Classrooms

Class	Design Challenge	Days of Observation (Before and After Design Challenge	Days of Focal Observation (During Design Challenge	Total Days of Observation
Eighth Grade Science	Battery Design Challenge	9	3	12
	Solar Car Design Challenge	4	4	8
High School Engineering Design	Timer Design Challenge	7	11	18
	Stool Design Challenge	12	6	18
High School Biomedical Engineering	Hip Implant Design Challenge	13	12	25

Research Context and Participants

Participants for this study were two teachers, one assistant teacher, and three classrooms of students in two schools located in two mid-western cities.

Fairview School[2]. I observed two classes at Fairview School, an eighth grade science course and a high school engineering design course (grades 9-12). Dr. Meyers taught both classes and was assisted in the engineering design course by Mr. Rana, a technology teacher and former engineer. Fairview School is an independent school serving 520 students in grades 6-12. The school is 60% white and 40% students of color[3]. 19% of students receive financial aid. The first class was an eighth grade science course and included 15 students (8 female, 7 male). These

---

[2] All school names, teacher names, and student names are pseudonyms

[3] Fairview school's publicly available data includes the percentage of students of color and percentage of white students. Science and Technology High Schools' publicly available data includes the following categories to identify students' racial background: Hispanic, Asian, Black, mixed race, Native American, and white.

students participated in engineering design projects as an integrated part of their science course. The second class, "Applied Engineering Design" was a high school course for students in grades 9-12. This course was offered as an elective. 20 students (18 male, 2 female) took the course. Data collection in the eighth grade class at Fairview school took place from November 10, 2017 through December 15, 2017. Data collection in the high school class at Fairview School took place from January 8, 2018 through March 22, 2018.

Science and Technology High School. The third class was a 10th-12th grade biomedical engineering course at a public charter school in a large mid-western city. Ms. Walsh was the teacher for this course. Science and Technology High School has an 87% graduation rate and serves 490 students in grades 9-12. More than 50% of the school's population identifies as white (52.8%), and 15.9% identifies as Hispanic, 4.7% identifies as Asian, 17.6% identifies as Black, 3.7% identifies as mixed race, and 0.4% identifies as Native American. The biomedical engineering class that I observed contained 20 students (9 male, 11 female). Data collection at Science and Technology High School took place from April 12, 2018 through May 16, 2018.

Rationale. These school sites were chosen because they were the only secondary classrooms I could find where I could observe teachers enact their own engineering curriculum. (I observed one lesson in each classroom before I finalized my site choices to learn about the goals and instructional design of each course.) Many schools in the area offered intermittent engineering design projects, pre-packaged or online engineering courses, or engineering after-school programs but students were not taking engineering courses for full credit and teachers were not designing and implementing their own engineering curriculum. I found both classrooms using internet research and through pre-existing connections in my university network, looking for teachers of engineering within driving distance that taught middle and high school classes using their own curriculum (instead of pre-packaged curricula or engineering design kits). The teachers from both schools were contacts given to me by my advisor.

Focal participants. Table 2 presents data on the 12 focal participants in the study. In total, there were five male participants and seven female participants. Eight participants identified as white, two as mixed-race, one as Black and one as Latinx. None of the students at Fairview School said that they had participated in an engineering course, summer camp, or after-school program before although several students indicated that they had engineering-related experience. Rick had experience with building. Emma had worked in a science laboratory and Matt worked with 3-D printers in his spare time. The focal participants at Science and Technology High School had all taken an introductory engineering course as freshmen. Ella had also taken one aviation course. Three students had experience in medicine. Jenny and Meg had completed CNA training and Sofia read medical articles with her father (a dentist).

One of the focal students, Matt, originally consented to interviews but due to illness and schedule constraints later withdrew from any interviews outside of class.

Student sampling procedures. In each classroom, I sampled a group of four focal students. I worked with either Dr. Meyers or Ms. Walsh to choose a focal group. I looked for a focal group that displayed two qualities. First, I looked for students in mixed ability groups in terms of their engineering design ability as shown in previous engineering design work. Second, I looked for focal group members who were willing to share their ideas with a teacher while they worked and I asked the teacher to choose students who would benefit by sharing their ideas with an observer (opposed to students who preferred to process their ideas alone). In all cases, I deferred to the teacher's recommendations as I selected students.

Table 2. Focal Participant Details

Engineering Design Course at Fairview School

Name	Grade	Racial/Ethnic Background	Gender	Engineering-Related Experience
Emma	12	white	female	- worked one summer in an environmental science laboratory
David	12	white	male	- no engineering-related experience
Rick	12	mixed race	male	- experience with building (a playground, a canoe, work on a farm)
Matt*	12	presented as white	presented as male	- experience with engineering-related hobby, building and maintaining 3-D printers

Eighth Grade Science Course at Fairview School

Name	Grade	Racial/Ethnic Background	Gender	Engineering-Related Experience
Grady	8	white	male	- no formal engineering-related experience
Mia	8	Black	female	- no formal engineering-related experience
Olivia	8	mixed race	female	- no formal engineering-related experience
Ethan	8	white	male	- no formal engineering-related experience

10th-12th Grade Biomedical Engineering Course at Science and Technology High

Name	Grade	Racial/Ethnic Background	Gender	Engineering-Related Experience
Jenny	12	Latinx	female	- completed freshman intro to engineering course -Completed Certified Nursing Assistant (CNA) training

Meg	12	white	female	- completed freshman intro to engineering course -Completed Certified Nursing Assistant (CNA) training
Ella	11	white	female	- completed freshman intro to engineering course and a course in aviation
Sofia	11	white	female	- completed freshman intro to engineering course -Read medical articles with her father (a dentist)

Note. Matt did not participate in any interviews.

Data Sources and Collection

I collected five sources of data for this study: videos (and transcripts) from small-group student interaction, transcripts from think-aloud interviews, transcripts from general student interviews, fieldnotes from classroom observation, and artifacts (documents) from observed lessons (including student work).

The focal data were transcripts from student think-aloud protocols, transcripts from general interviews with focal students, and videos (and transcripts) from instances of small group engineering design work. Focal data also included student work samples and other artifacts from the instances of group work. I relied on the focal data to describe how students worked with engineering texts within engineering design projects. Working with the teacher, I collected focal data on days where students were engaged in group work during an engineering design challenge. During these lessons, my data collection (transcripts, interviews, and artifacts) focused on the work of the focal students. When it was convenient, I also took fieldnotes from observations of the other students in class, asked them questions about their work, and collected work samples.

The contextual data included fieldnotes and artifacts from the days of instruction before and after engineering design work along with interviews from the teacher. This contextual data allowed me to situate the data from engineering design activities within the context of the course. In what follows, I will explain the sources of focal and contextual data in more detail and how they align with my research questions.

Focal data: Sources and collection. I collected three kinds of data from a focal group of students (n=4) in each classroom: interviews, transcripts, and artifacts. Focal data came from days when students were participating in an engineering design challenge.

Interviews. I administered a semi-structured general interview and four think-aloud interviews with each participant. The general interview followed a semi-structured interview protocol (see Appendix B) where I asked students information about their educational background and interests related to engineering. For the four think-aloud interviews, during the first days in each classroom, I asked the focal students to verbalize their thoughts as they read through two different engineering texts in one sitting. (See Appendix A.) At the end of the unit, I repeated the same procedure with the same texts. I determined which texts to use after consulting with Dr. Meyers and/or Ms. Walsh. I aimed to collect the texts that students that would work with the several times during the engineering design challenge.

Transcripts. On the days of focal observation, I recorded the work of the focal students (both audio and video recordings). Then I made transcripts from these data. The transcripts explained what happened during the group work and provided information about how the group understood the texts that they read and wrote as they designed and how they used text to support their design work. During the focal instances of group work, I also prompted the students to verbalize their thoughts and discuss their ideas. During these times, I chose relevant questions from the think-aloud protocol (see Appendix A). On the days of the focal observation, I also collected fieldnotes.

Artifacts. I collected samples of student work as well as copies of lesson plans and documents used on the days of the design challenge.

Text sampling procedures. During the recorded instances of collaborative group work, I collected all the texts used. As much as possible, I collected physical copies of these documents. In other cases (for example, when students were searching websites), I noted the nature of the text in my observation notes (for example, which search engines used, which web pages referenced, and for how long). During the days of observation before and after the recorded instances of collaborative group work, I also collected a complete sample of all the texts that were used or assigned by the teacher. As I observed the students in the lesson, I collected a full sample of texts that were used by the focal students.

Contextual data: Sources and collection. My second research question asked "What opportunities do middle and high school students have to learn literacy skills, knowledge, and practices in engineering design classrooms? How does literacy engagement appear to be influenced by the instructional context?" In addition to the focal data above that addressed this question, I also collected contextual data that addressed this research question. The contextual data included fieldnotes and artifacts taken from days of instruction before and after a design challenge.

Videos and fieldnotes. I recorded each class period that I observed before and after the design challenge. I also collected fieldnotes. Fieldnotes documented the classroom observations and captured "sketches" (Emerson, Fretz, & Shaw, 2011), or multi-sensory portraits, that focus on the lesson delivery and include a description of the actions of teachers and students, presentation of materials, excerpts of dialogue, teacher and student reactions, and other elements of the instructional context as the lesson is delivered. Fieldnotes also included any information from brief discussions I had with the teacher before, after, or during class. (Any brief discussions that occur in class occurred only during free time and did not interrupt the normal course of instruction. During some observations, I was only able to take “jottings” (Emerson, Fretz, & Shaw, 2011), or notes and sketches. All jottings were transcribed into typed fieldnotes within 24 hours.

Artifacts. Artifacts include pictures of classroom activities, samples of documents used in class, and other documents.

Data Coding and Analysis

I used Constant Comparative Analysis (Glaser & Strauss, 1967) to analyze the data iteratively and recursively to “generate a theory that is integrated, consistent, plausible, and close to the data” (Glaser & Strauss, 1967, p.103). I began my analysis of the data immediately after the first day of observation by organizing and transcribing the data that were collected. During the data collection, I wrote analytic memos at least once a week to record information about the process of data collection and my thoughts on what I was observing in the classroom with attention to the “emergent patterns, categories and subcategories, themes, and concepts” in the data (Saldaña, 2009, p.33).

Transcription. First, I transcribed the interviews and the videos of engineering design work during the days of the design challenge. During this first exploration of the data, I enhanced my own understanding of what occurred in the classroom as I saw the data from a different point of view. I began coding immediately by creating memos as I was transcribing to discuss the possible codes and patterns that I noticed as I transcribed the data from each case.

After transcribing the focal data set (data taken during the days of the design challenges in all three classrooms) and looking over the memos from the days of observation and days of transcription, I began to notice patterns in the data around the purposes for reading and writing during the design challenges. I noticed that students read and wrote to understand more about the user of their design and the larger social problem that the design might solve. (This pattern later became "delimiting the problem," one of three focused codes.) I noticed that students were also reading and writing to understand if (and how) their design worked (or would work). (This pattern later became the focused code "realizing the solution.") Finally, I noticed that students were reading and writing to find evidence that their design idea would work well and solve a social problem. (This pattern later became the focused code "warranting the design.")

Initial coding. After the data were transcribed and organized, I began a second pass at the data, engaging in a process of line-by-line coding, using action words to explain what was happening in the data, and looking back over these action words in search of themes (Charmaz, 2006). At this stage, patterns were "provisional, comparative, and grounded in the data" (Charmaz, 2006, p. 48). I focused only on a subset of data from each classroom (transcripts, interviews, artifacts, and fieldnotes from one or two days of focal observation in each classroom). The initial codes explained the actions happening in the focal group as they read, wrote, and designed their prototype. The initial codes included "proposing a modification," "raising a question about the design," "explaining the design," and "visualizing how a user would use the design."

Focused coding (third pass). In the third pass at the data, I moved from this initial coding to a system of more focused codes, or "substantive categories" that fit the data (Maxwell, 2013). At this stage, I considered each category of data separately, reading the data to notice patterns and possible codes.

Transcripts of group work and student work artifacts. I looked back at the results of the line-by-line coding guided by the following questions:

1. How have students understood each of the texts they have used? Is this understanding confirmed by *in situ* questioning of students? Is there evidence of what students know and can do in their work product? If so, how?
2. Is there evidence that students have faced an obstacle or challenge to understanding a text? If so, what challenges might they have faced?
3. Is there evidence of knowledge, skills, or practices that are being leveraged in their work?

Think-aloud transcripts. I read the think-aloud data guided by the following questions:

1. What literacy skills do students rely on to read engineering texts?
2. What knowledge and/or ways of thinking guide students as they read engineering texts?
3. When comparing early think-alouds to think-alouds at the end of the course, what has changed? What knowledge, skills, or practices have evolved or emerged?

General student interviews. I read the general student interviews to understand the previous engineering experiences of focal students, what they enjoyed about engineering, what challenged them, and any other themes related to their background and interests that may have affected their work in class.

Contextual data: Fieldnotes from classroom observation. I read the fieldnotes from classroom observation (before and after group work) and looked at classroom artifacts to see if themes and patterns had emerged. I noted the ways that the emergent themes from the focal data were represented in the contextual data. I discussed how these data contextualized the emerging themes in the focal data in my analytic memos.

Focused coding (fourth pass). At this point, I went over my memos, the initial coding, and memos from the third pass at the data, and began to notice the relationships among the initial grounded codes and the three patterns I had noted after completing the transcription of the data. I began to nest instances of actions that I noticed in the initial coding (e.g. “raising a question,” “explaining the design”) under one of the three purposes for reading: “delimiting a problem,” “realizing a solution,” and “warranting a design.” (See Table 3.)

Some of these instances were double-coded. For example, while the students were discussing several sketches they had made of possible stool designs, Rick said “We’re thinking like a double step stool. Like a step stool and depending on your height you could sit on either edge” (Transcript, March 13, 2018). Here, Rick was “proposing a design” (a sub-code) when he said “we’re thinking a double step stool.” He also was “visualizing how a user would use a design” (another sub-code) when he imagined how users with different heights would use the design. This whole turn of talk would be coded as “delimiting the problem” because he was considering the needs of a user population with varied heights. It would also be considered “warranting the design” because he proposed that the group go with the two-step stool as their design using evidence of how the stool might fit the varied heights of the user population.

Table 3. Descriptions of the Three Focused Codes

Code	**Operational Definition**	**Data Exemplar**
Delimiting a social problem	Data that is about user need and how to design to fit user need. Data includes visualizing how a user might use a design, proposed modifications to an existing design based on user need, questions raised about how to fit user need, and other attempts to understand the social problem (e.g., discussions of how to collect data about a user population).	*Focal student explaining a sketch of a stool:* Like if it's [the ledge is] here and someone's trying to use it [the stool] as a step stool, we don't want them like stepping over their tools, right? Do you know what I mean? (Transcript, March, 13 2018)
Realizing a design solution	Data that is about at how the design works (the physics of the device). Data includes questions raised about the physical functioning of a design, proposed modifications based on data that reflects physical operation, and any reading or writing with machines or measurement devices designed to understand how a design works. Data does not include predictions of how a design would work for	*Two students begin a CAD drawing of a stool design:* Student 1: We have 30 by 30. So I converted it [the settings] to centimeters. Then we have the surface area, right?

	a user that do not discuss the physics of the design. (That is delimiting.)	Student 2: I think we'll be able to fit it all in. (Transcript, March 13, 2018)
Warranting a design solution	Proposed designs and proposed design modifications (elements of that final design idea). Includes ideas with evidence (which are double or triple-coded depending on the nature of the evidence, whether it refers to the user and/or the physical function). Includes design ideas without evidence or with weak evidence.	*Student proposes a design idea:* So you guys want a leaning stool? I don't know what it is. It sounds cool. (Transcript, March 13, 2018)

Triangulation. In the fourth pass at the data, I worked with the data from each case, applying the system of codes, nesting instances of the sub-codes (focused on the action being performed) under the "top-codes" of delimiting, realizing, and warranting (focused on the purpose of that action). Within each case, I triangulated across the different types of focal data (transcripts of small group work, interview transcripts, and artifacts). Then I looked across the three cases, for ways that these codes appeared in each of the three classrooms—if data from a different class or a different type of data enhanced, challenged, or complemented the coding scheme. I also looked for disconfirming evidence across the data. When needed, I also consulted the contextual data to understand what factors in the instructional context may have influenced the focal data.

These codes allowed me to analyze the ways that students were using text (and references to text) to engage in three purposes: to delimit a problem, realize a solution, and warrant a design. Within each of these three "top-codes," I had also marked the specific actions in and around text that corresponded to each purpose. The coding captured instances where students were able to read, write, and speak about text in ways that achieved these purposes but also captured attempts to read, write, and speak about text to achieve the same purposes that were less successful: instances where students expressed frustration verbally with certain text, abandoned the reading and writing they had begun, or did not engage with texts they were given to help them design a solution.

Limitations

Although I worked to design a thorough and rigorous data collection and analysis program, two limitations remain. First, my data collection focused only on one or two engineering design experiences at each school site. Engineering literacies are likely to differ according to the nature of an engineering design challenge and this study was only able to collect data to illustrate a very limited scope of the range of engineering design challenges that could occur in engineering classrooms. Second, this study did not capture growth (whether as a result of learning or development) over time. It was not able to explain the nature of literacies that students developed through their years of schooling or even over the course of one full year of school. Keeping these limitations in mind, there was still great value in exploring how three classrooms of students engage in engineering literacies. This work will be some of the first work to explore student literacy learning in middle and high school engineering. Through a small number of cases, this work can explain how engineering reading and writing supports students to engage in engineering inquiry and develop literacy knowledge and skills for college, career, and life.

Risks to Participants

One risk to participants was the risk that participant identities could be learned by a third party. To prevent this, participants received a pseudonym that was used in the notes, fieldnotes, and transcripts. On occasion, I shared the data, as well as audio recordings, with the classroom teachers in the study and my university advisor. No other persons had access to the audio recordings or any de-identified data.

Major Assertions

The study found three literacy practices at work across the three classrooms: reading and writing to delimit a problem, reading and writing to realize a solution, and reading and writing to warrant a design. Although these were the literacies that supported students to engage in the process of engineering design during the design challenges, patterns in the data also presented instances where the texts and tasks of the classrooms did not enable students to engage with these literacy practices (in delimiting, realizing, and warranting). Across the cases, these instances of "disconnect" between reading and writing and the literacy practices (delimiting, realizing, and warranting) occurred with engineering texts that were not common to other subject-area classrooms, where students often struggled to understand how to read and/or write a text as well as why to do so. The "disconnect" also occurred with more familiar school texts, such as articles, but in different ways. Students read (and wrote) these texts, often with comprehension and fluency, but observation and interview data showed that students did not use these texts to make decisions about their design. The reading and writing did not seem to influence student engagement in the engineering design process. Therefore, I present the findings in the following chapters (Chapters 4-6) with a short overview of the way that students engaged in delimiting, realizing, and warranting through text and then focus the presentation of the findings on three patterns in text use that characterized literacy engagement across the three classrooms. Chapter 4 presents an analysis of student engagement with texts that were more common to the engineering classroom than other content-area courses (texts such as diagrams, documentation, and sketches) and shows that students struggled to read and write these texts during the engineering design challenge. Chapter 5 presents an analysis of student engagement with familiar text (such as articles) and shows that while students comprehended these texts, they did not always use the information in the texts to create or improve a design solution. Chapter 6 presents an analysis of student engagement across multiple texts showing how students used text to argue that their design worked for a particular purpose and fit user need.

Chapter 4 Overview of Engineering Literacy Practices and Student Engagement with "New" Engineering Texts

In this study of engineering reading and writing engagement in design challenges across three secondary classrooms, I found two key patterns in literacy engagement. First, I found similar patterns in the purposes for reading and writing across all three classrooms. When students engaged with the texts of the engineering classroom, they did so for three central purposes during the design challenges: to delimit a problem, realize a solution, and warrant a design. I will begin this chapter with an overview of engineering literacy practice across the three classrooms and define engineering literacy practice as reading and writing to delimit a problem, realize a solution, and warrant a design. This overview will contextualize the presentation of data in all three findings chapters (Chapters 4, 5, and 6).

Second, I found that some of the texts and tasks of each design challenge enabled students' ability to engage in engineering literacy practice (delimiting, realizing, and warranting), while other texts and tasks did not seem to do so to the same degree. There were three patterns in engagement with the texts and tasks of the design challenge that will be the focus of Chapters 4, 5, and 6 respectively: reading and writing the texts unique to the work of engineering, reading and writing traditional school texts for the purposes of engineering, and reading and writing across multiple texts. In this chapter, I will focus on student engagement with engineering texts that were not common to other subject areas such as documentation, sketches, and diagrams. A focus on the nature of the texts, students' experience with text, and the affordances of instructional tasks across the findings chapters will highlight the nature of text and the qualities of instructional support that did or did not engage students in delimiting problems, realizing solutions, and warranting their design. Overall, I found that students warranted their designs when they had texts with useful information for warranting and examples of how to use evidence. When students did not have texts with useful information or when they did not have examples of how to use text, they relied on their likes and dislikes instead of textual evidence to warrant their designs or they copied text without explanation or rationale to create warrants.

Realizing, Delimiting, and Warranting: An Overview of Purposes for Reading and Writing Across Three Classrooms

The students in all three classrooms engaged with text during the design challenge to learn more about how their design solutions worked and the social need they were designed to fulfill. These text engagements required students to read and write within and across several genres and modes of text during the design challenge. Table 4 includes examples from several genres of texts that students read and wrote during the design challenge and includes sketches, data tables, documentation, diagrams, articles, tutorials, and reports. Although there were some genres of text that were less common across the three classes (e.g., interview notes, CAD drawings) students read and wrote many of the same text types across all the classrooms.

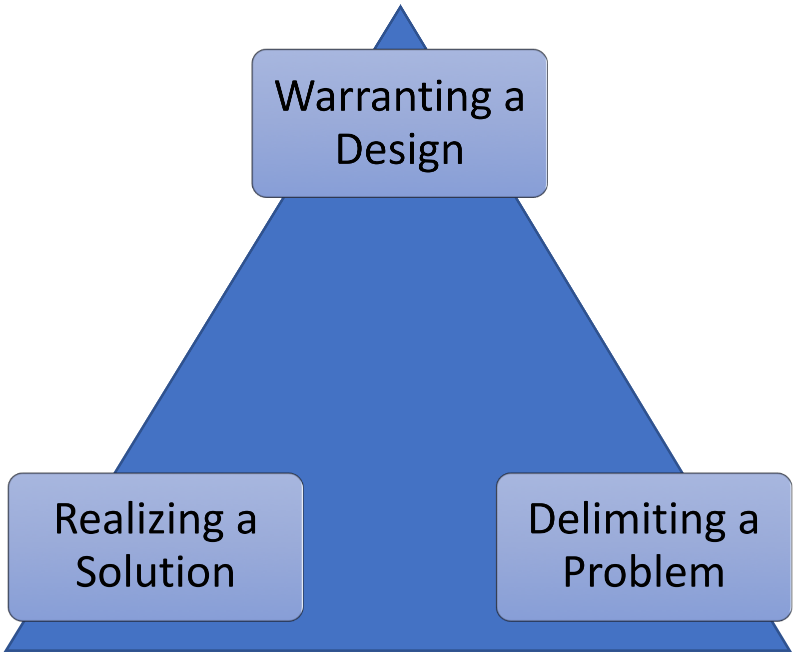


Figure 1. Literacy practices in engineering design challenges of three classrooms

Table 4. Examples of Text Types Across Three Classrooms

Text Type	**Example from Eighth Grade Science**	**Example from High School Applied Engineering Design**	**Example from High School Biomedical Engineering**
Sketch	Sketch of initial solar car design	Sketch of two-step stool	Sketch of hip implant
Interview notes	n/a	Interviews with robotics students	n/a
CAD drawing	n/a	Stool design	n/a
Data table	Table of battery voltage	Table of height and popliteal length	Table of properties of biomaterials
Design Brief	Design brief for the battery design challenge	Design brief from "The 20-Second Timer"	Design brief for the hip implant design solution
Notes and documentation	Notes voltage produced by solar cell	Notes from 3 time trials of the cardboard timer	Notes on hip implant design
Diagrams	Solar car diagram	Diagrams representing engineer problem-solving	Hip implant diagram
Student presentation	n/a	Poster of initial stool design	Scripts for final presentations
Article or non-fiction excerpt	Packet of metal readings	Article about Aeron chair	Article abstract
Tutorial or simulation	Instructions for battery lab (paper-based)	Online tutorial: Easel software	Hip implant surgical simulation
Graph, graphic	Graphic of heavy metal pollution	n/a	Graph from article about titanium implants
Report or reflection	Report with description of battery design for campers	Reflection on design solution	n/a (oral reflections)
Machine output	Voltmeter	CNC machine	n/a
Webpages	n/a	CNC machine website	Medical device catalog

Note. Table does not include texts used by the teacher for presentation (e.g., PowerPoint slides) or homework

Students' reading and writing had one over-arching purpose—to warrant their designs (and design choices) with evidence from this diverse body of texts. To warrant their designs, students drew (and attempted to draw) conclusions from text to build evidence that their designs both worked efficiently and met a user need. Figure 1 explains the literacy practices that I drew from the cross-case analysis. The over-arching practice of warranting a design was supported by two literacy practices: delimiting a problem and realizing a solution. Each practice included a set of literacy knowledge and skills and students read and wrote across many different text types to engage with each practice. These practices were inter-woven. To make a case for a particular design, students did not only argue that their design was efficient or that their design met user need. They worked to do both.

This figure has some similarities to the three component ideas of the engineering design cycle in Appendix I in the NGSS (NGSS Lead States, 2013): defining and delimiting engineering problems, designing solutions to engineering problems, and optimizing the design solution. It makes sense that the purposes for reading and writing across the three classrooms align with the purposes for engaging in the engineering design cycle; literacy engagement should support students to engage in engineering practices. However, my figure, which focuses only on literacy practice and not on engineering practices, has three notable differences. First, I include the literacy practice of "realizing a solution" (instead of "designing a solution") to draw attention to the ways that reading and writing can illuminate the physical properties and physical function of a design solution. "Designing a solution" happens through all three literacy practices represented in the figure. Second, I include the practice of warranting, the literacy practice of gathering and interpreting evidence to "make a case" for the elements of a particular design solution. In addition to the physical product or design that results from engagement with the engineering design cycle, I present evidence in these chapters (with specific attention to warranting in Chapter 6) that students also created an intellectual product, a warrant for their design supported by textual evidence. Third, optimization is not included in my figure because it is a natural consequence of reading and writing to delimit, realize, and warrant. Delimiting the problem and realizing the solution results in textual evidence that can be used to optimize a design. Warranting a design includes the ability to present textual evidence and a rationale for how this evidence has created an optimal design solution.

Reading and writing to realize a solution. Students read and wrote to realize a solution when they engaged with text to understand how a design functioned— when they used text to understand the materials that composed their design and/or how these materials operated under different conditions. For example, students in the high school biomedical engineering course sketched their designs for a hip implant and used these sketches to choose materials for a prototype. (See Figure 2.) The students had to use the sketch they had made to choose simple materials for the prototype that would correctly represent each material in their design solution.

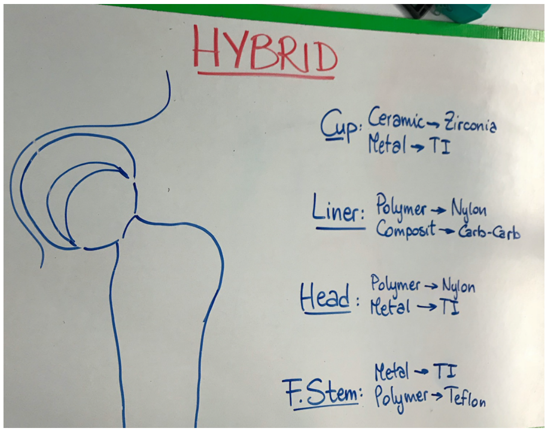


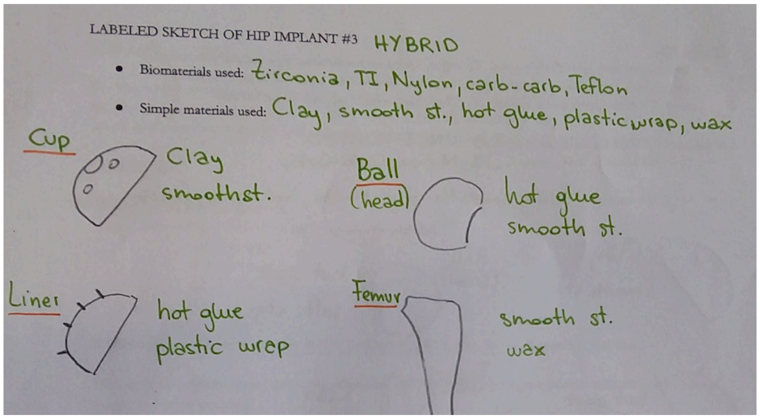
Figure 2. Group sketch of hybrid hip implant

The students had the following exchange as they chose simple materials for their prototype:

> Sofia: The femoral stem it's ... durable so it's going to be hard.
> Meg: So the femur stem thing is metal, right?
> Sofia: Yeah, it's metal and polymer so either the polymer is the base and we have something else outside or the polymer is the thing outside.

> Meg: We could get more foam and make it look like metal, like tin foil or silver paint 'cause like since the metals we are using are made out of those things so you can combine them two to make it look like this [the sketch].
> (Transcript, May 1, 2018)

Sofia and Meg discussed the femoral stem. On the sketch, they had not indicated what part of the stem was titanium and what was Teflon. In this exchange, Sofia wanted to find a metal that represented the durability of the materials in the femoral stem ("it's durable so it's going to be hard"). Sofia also wondered which material would be used for the base of the femoral stem, and which material would be on the outside ("either the polymer is the base and we have something else outside or the polymer is the thing outside"). Meg offered an idea, that the students use aluminum foil or paint to represent titanium ("we could get more foam… tin foil or silver paint"). This way, the prototype would be rigid (because of the foam) but also look like metal (because of the aluminum foil or paint). Later in class, the students decided to use foam for the titanium and wax to represent Teflon and they decided that the titanium would be the base of the femoral stem (Transcript, May 1, 2018). The students drew new sketches that included all the simple materials they had chosen (See Figure 3.) Both the sketches and the discussion around the sketches to choose the correct material supported the students to realize their design, to understand what the materials in their hip implant were, the properties of these materials, and how the materials worked together in the hip implant.


LABELED SKETCH OF HIP IMPLANT #3 HYBRID

- Biomaterials used: Zirconia, TI, Nylon, carb-carb, Teflon
- Simple materials used: Clay, smooth st., hot glue, plastic wrap, wax

Figure 3. Sketch of hybrid hip implant with simple materials

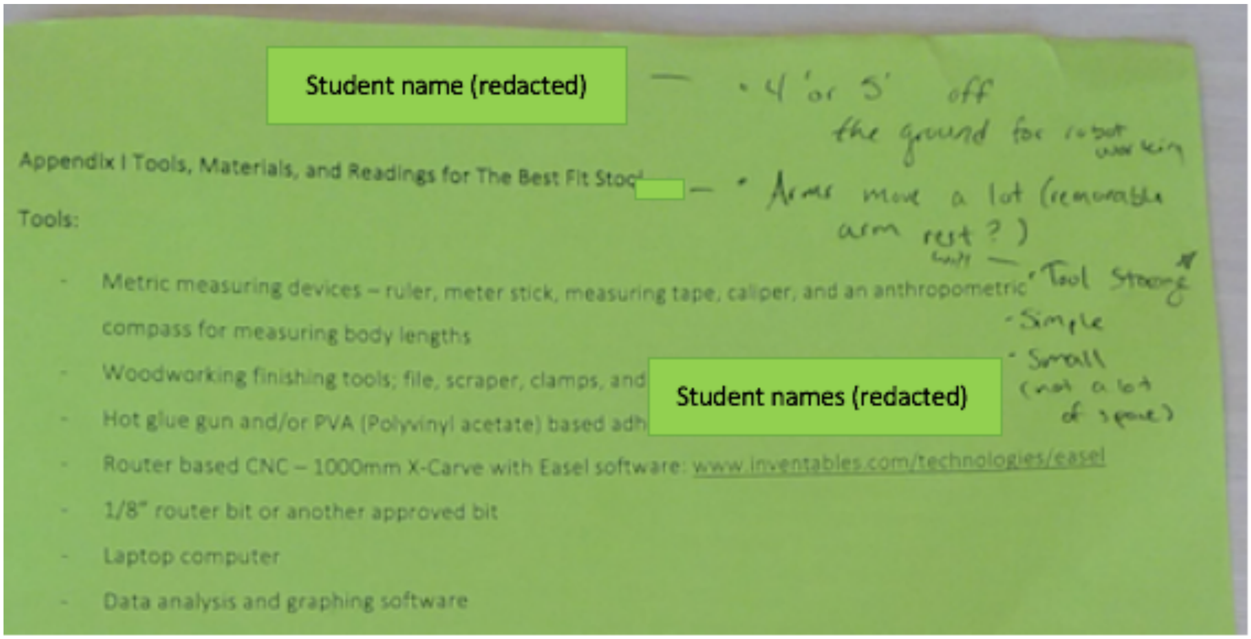
Across the three classes, students discussed what their solution was and how it worked as they referred to texts and their prototypes. Table 5 presents the number of total utterances that students made to realize their designs across the five design challenges in three classrooms. Utterances included questions and statements about how the design worked. For example, during the hip implant challenge when the students were choosing materials, Sofia was reading a table of biomaterials and said “And Teflon is a polymer. And we're using it because it's.... resilient...” (Transcript, May 7, 2018). This counted as one utterance that supported students to realize their design because Sofia was discussing the properties of a biomaterial that the students could have used in their hip implant design. Not all utterances recorded referred to a text. Utterances also referred to the students’ prototype. The table shows that realizing the solution was a major theme in the students’ discussion across the three classes.

Table 5. Number of student utterances to realize the solution

Class	**Design Challenge**	**Total Instances**	**Average (Per Day)**
High school engineering design	20-Second Timer	781	78.1
	Stool of Best Fit	172	28.7
High school biomedical engineering	Hip Implant Design Challenge	155	17.2
Eighth grade science	Battery Design Challenge	91	30.3
	Solar Car Design Challenge	215	53.8

Reading and writing to delimit a problem. Students read and wrote to delimit a problem when they engaged with text to understand the multi-faceted social problem that resulted in a user need— when students used text to narrow the focus of a complex problem on a set of issues or concerns that they wanted their design to address. For example, students in the high school engineering design course who were designing a wooden stool for use at a robotics competition read interview notes to understand if (and how) stools made people’s lives easier.

First, the students interviewed three members of the robotics team (Fieldnotes, March 13, 2018). One student (David) took notes from the interviews in the top right-hand corner of a document from class (the design brief). David wrote the name of the interviewee as well as a few words about what he or she said (“simple, arm rest, small”). He marked one piece of information with a star and he also recorded his own design ideas related to the information (removable arm rest?). (See Figure 4.)



Student name (redacted) — • 4' or 5' off the ground for robot working

Appendix I Tools, Materials, and Readings for The Best Fit Stoo [redacted] — • Arms move a lot (removable arm rest ?)

— • Tool Storage *

• Simple

• Small (not a lot of space)

Tools:

- Metric measuring devices – ruler, meter stick, measuring tape, caliper, and an anthropometric compass for measuring body lengths
- Woodworking finishing tools; file, scraper, clamps, and
- Hot glue gun and/or PVA (Polyvinyl acetate) based adh
- Router based CNC – 1000mm X-Carve with Easel software: www.inventables.com/technologies/easel
- 1/8" router bit or another approved bit
- Laptop computer
- Data analysis and graphing software

Student names (redacted)

Figure 4. Notes from interviews with three robotics team members

Writing notes was a way for David to record the information for further use. David also used his notes to process information from the interviews, annotating his notes with a star and writing down design ideas. He wrote “4’ or 5’ off the ground for robot working,” taken directly from what the robotics students were saying, as well as “arms move a lot” and “simple, small (not a lot of space). These were issues the robotics students discussed in their interviews (Transcript, March 18, 2018). After he read over the interview notes, David marked “tool storage” with a star as an issue that he would like to attend to in the design. David also included “removable arm rest?” next to his notes on “arms move a lot.” When he read over his notes, he recorded this design idea that was aligned to the issues the robotics students brought up in their interviews. David wrote and read interview notes to delimit a problem as he recorded and analyzed interview data to draw out design issues and brainstorm aspects of his design solution that could solve these issues.

Table 6 presents the number of total utterances that students made to delimit the problem across the five design challenges in three classrooms. Utterances included questions and statements that were about the user or user need. For example, during the "Stool of Best Fit" design challenge, Matt remarked that "Maybe our subgroup should just be… the robotics coach" when he was reading a table of measurements of the robotics team members (Transcript, March 16, 2018). This counted as one utterance that supported students to delimit the problem because Matt was putting forth an idea for who should be their target user based on his reading of the data table. Utterances also referred to a prototype, such as when Emma looked at the cardboard stool prototype and asked "Is everyone's butt gonna fit in that area?" (Transcript, March 19, 2018). Emma was considering the needs of their subgroup of users as she interacted with the prototype so this counted as an utterance to delimit the problem.

Table 6. Number of student utterances to delimit the problem

Class	**Design Challenge**	**Total Instances**	**Average (Per Day)**
High school engineering design	20-Second Timer	32	3.2
	Stool of Best Fit	140	23.3
High school biomedical engineering	Hip Implant Design Challenge	8	0.73
Eighth grade science	Battery Design Challenge	60	20.0
	Solar Car Design Challenge	4	1.0

The number of utterances varied across the design challenges. The instructions for each design challenge sometimes specified a user (such as in the "20-Second Timer" project) or sometimes did not (such as in the solar card design challenge) and this could have accounted for some of the variation across classes.

In some cases, students read and wrote to delimit a problem and realize a solution with the same text. In the example of David's interview notes (above), he used the notes to delimit the problem and draw out issues he would like to solve in his design (such as tool storage). He also wrote to brainstorm how the design might work to solve these issues (writing "removable arm rest" next to the interview data), which was writing that supported him to realize his design, to begin to imagine what the design might look like in order to solve a particular design issue.

Although David took interview notes on one of the first days of the design challenge, he was already warranting his design. He was visualizing his design solution (a small stool with storage and a removable arm rest) and using the interview data to build evidence that his design met the needs of the robotics team. The students sketching a hip implant were also beginning to visualize and warrant their design. They used the sketches to understand how their design would look and build evidence that their solution would be a durable hip implant. Working through the design challenge, both groups of students read and wrote to collect evidence that their design worked well and met the needs of the user. They read and wrote to warrant their designs. Therefore, although Figure 1 represents warranting as the top of the triangle it was not a practice that only occurred after students read and write to delimit a problem or realize a solution. Instead, students grew in their ability to warrant over the course of the design challenge (and through successive iterations of the design cycle) as they developed evidence that their design worked to solve a problem through reading and writing across multiple forms of text.

Warranting, realizing, and delimiting: Conclusion. Across all three classrooms, students used text to delimit a problem, realize a solution, and warrant a design. This was engineering literacy practice and the purpose of using the text in all three classrooms. Yet, as the findings will show, the texts and tasks across the three classrooms did not always support students to warrant their designs, delimit a social problem, or realize their solutions. The findings in the following chapters will focus on the nature of text, student's experience with text, and the qualities of instructional tasks to examine the nature of texts and the quality of tasks that might enable students to engage in these engineering literacy practices. In this chapter, I will present evidence of student engagement with "new" text— engineering texts that are more common to engineering than other subject areas.

Students Work with "New" Texts to Design a Solution

Across all three classrooms, the texts that were most challenging for students to work with were texts that were more common to the engineering classroom than the other subject area classrooms. In this chapter, I present three examples of these engineering-specific texts: documentation (of time trials), a sketch, and a diagram. Students read and wrote most of these "new" engineering texts to realize a solution: to plan the physical properties and design of an engineering solution, to collect and interpret data, and to read the data and designs of others. All three examples come from the middle and high school classes at Fairview School. (The course at Science and Technology High School also included sketches in the design challenge, but I will discuss this sketching in Chapter 6.) The data from Fairview School illustrates the challenge of reading and writing in a new field. All eight focal students from Fairview School were good readers and writers in other classes and their attempts to read and write documentation, sketches, and diagrams show their ability to take initiative to work with unfamiliar text. However, as all three data exemplars in this chapter demonstrate, students struggled in their first attempts to read and write these new texts. The students did not understand how to write sketches that they could use to work with design materials. The students could not comprehend diagrams or apply information from diagrams to their design. The students did not know that certain texts (such as documentation) could help them understand how their design worked. In short, tasks of the classroom enabled students to initiate reading and writing during the design challenge but the students did not have the engineering literacy skills to sustain reading and writing to create and improve their design solutions. The focal students' struggle to read and write engineering text shows the challenge of understanding the form and function of the texts of engineering, even for strong readers and writers who are new to engineering.

Documentation of time trials: Students struggle to improve a design solution. During "The 20-Second Timer" design challenge in the high school engineering design class, the focal students (Matt, Emma, David, and Rick) built a timer out of cardboard and other materials for Ms. Bethany, the teacher in the school's mindfulness center. The timers were to be used as a meditation activity. The design solution that the group decided on during the second day of the challenge was to build a series of cardboard ramps inside a cardboard box top. A ball bearing would roll down the ramps, taking 20 seconds, and then hit a bell. Over the next few days, the students added on cardboard housing for the bell, a cardboard "switch" that started the ball rolling and cut a series of cardboard "petals" to decorate the box. (See Figure 5.)

Figure 5. Cardboard timer

The majority of the time during the design challenge was spent getting the ball to roll down the ramp consistently. The students manipulated the positioning of the ramps, glued down smoother cardboard, adjusted the bell, and engaged in several time trials. During this time, students began to document three of their time trials, writing that could have helped them improve their timer. However, they did not continue documenting or refer back to their previous documentation during the final days of the design challenge. Students spent most of their time on these days observing the timer and making "on the spot" modifications but were unable to make the timer work consistently, which only made them more confused about how their timer worked.

On the final day before their presentation of their timer, Matt, Emma, David, and Rick spent the entire period wondering why the timer would not work the way they wanted it to. The ball stopped, fell off the ramp, or did not make it down the ramp in the desired time. The students wondered aloud what was happening 33 times throughout the class period (e.g, "That's weird" or "What changed here?"). Below are some excerpts of the discussion they had in between time trials:

> *(Time trial. The ball gets stuck at the beginning of the third ramp.)*
> Rick: Oh no no
> David: Why is this happening? It's just like totally random. It's not really…
> *(Time trial. Ball stops on the second ramp.)*
> Rick: Alright, try two.
> David: I just don't understand how it changes.
> Emma: Me either. Like nothing about it has changed.
> *(Time trial. Ball gets stuck on the ramp.)*
> David: I don't really know like (chuckles)
> *(Matt touches the top of the box, squeezes.)*
> Rick: Stop stop stop. *(Rolls the ball down the ramp.)*
> Rick: Alright, so we have to fix that [the ramp].
> Emma: At least it looks cute *(chuckles).* I'm sorry. I'm just stressed out.
> Matt: It's generally just like a flaw in design.
> David: It's really... it's weird.
> (Transcript, February 1, 2018)

The students did not seem to understand the factors that affected the way the ball bearing moved and did not know how to fix their timer so that the ball would roll smoothly down the ramps as it had once or twice before. As an observer in the room, I noted many factors that could affect how timer worked including:

> - the angle of the ramp box on the support ramp (movement forward and backward) and position of the ramp box on the support ramp (movement side-to-side)
> - the position of the bell in the ramp box and the angle of the bell trigger (the housing around the bell)
> - the quality/smoothness of the cardboard used to make the ramps.
> - the quality and amount of adhesive around the ramps
> - the dimensions of the "speed bumps," the lines of hot glue the team had put on some ramps to slow the ball
> - the angle, material, length, and width of the two kinds of ramps (long straight ramps and c-shaped ramps)
> - the drop from one ramp to the other and the clearance for the ball to roll
> - the position of the ball on the starting ramp and the force used to start the ball
> - the sturdiness and angle of the table underneath the timer
>
> (Fieldnotes, January 19-February 2, 2018)

I also observed that the students sometimes touched or moved the box during the time trials, which would have affected the way the ball bearing moved down the ramp. Yet, the students in the focal group describe the movement of the ball as "totally random."

Both Dr. Meyers and Mr. Rana suggested reading and writing that would help students to collect data on their design and improve its efficiency. Mr. Rana suggested that the group use a video recording to gather data. "You could make a video of it and look back at the video and see what time you started and what time you ended…You'd have an exact time, if you're worried about starting it at a time" (Transcript, January 30, 2018). The students did not take up Mr. Rana on his idea to video record their timer. Dr. Meyers suggested the students document their designs during the instructions he gave to students at the beginning of class on three of the six days that students were building their design solutions:

> The only thing I ask is that you are documenting things, right? Make drawings. You can take pictures of the work you do and document that stuff as well too. You need to document your iterations (Transcript, January 18, 2018).

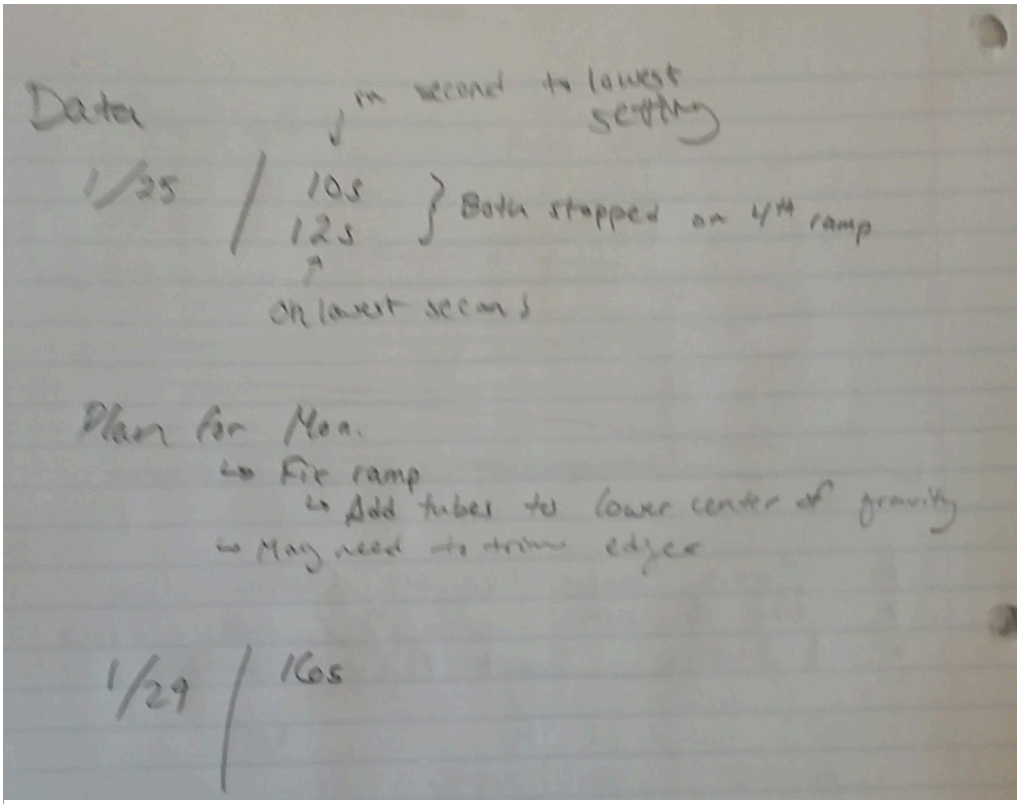
Also, as the students were working in small groups, Dr. Meyers reminded the focal students two times that they should document their iterations (Transcript, January 23, 2018). The students did write down two of the time trials (Transcript, January 25, 2018) and another single time trial (Transcript, January 29, 2018). They also included three notes (e.g. "stopped on 4th ramp") on their paper with the record of the three time trials. (See Figure 6.) On February 1st alone, the focal group had 45 time trials so they did not record the vast majority of their timings. The students also took pictures of their design at the end of each class, but I did not see them refer back to these pictures as they completed the design challenge.

Without a record of documentation, the students relied on "on the spot" modifications in the final days of the design challenge. For example, Emma made the following suggestion:

> So what I was thinking was... It looks like the glue over here [on the wall] is stopping it [the ball rolling] so we could... I don't know. We could cover the wall [with cardboard]. That's what I'm saying. (Transcript, January 29, 2018)

Emma's suggestion shows a pattern present in the communication around the cardboard timer: a student observed the timer at work, shared a single observation with the group, and then manipulated the timer in some way to improve it. On this day (January 29, 2018), the group shared nine different observations followed by a suggestion. The group also suggested modifications unrelated to observations, based on their prediction of how the timer might work (e.g. "We cut a slot here so it can push down. Does that make sense?").

The way that the group relied on single observations caused problems. Without standardized measurement, their observations did not always agree and over several days of the design challenge they did not remember all of what they did the day before. For example, the students



Data
↓ in second to lowest setting
1/25 | 10s
12s } Both stopped on 4th ramp
↑
on lowest seams

Plan for Mon.
↳ Fix ramp
↳ Add tubes to lower center of gravity
↳ May need to trim edges

1/29 | 16s

Figure 6. Focal group documentation of three time trials

forgot the position of the bell on the ramp from the previous day (Transcript, February 1, 2018). Also, in the example of dialogue above, Matt squeezed the box and Rick did not agree that the box needed to be touched or changed ("stop, stop, stop"). Matt also ripped off a section of the ramp when he observed that the ball was getting stuck, and the rest of the group disagreed that the ramp was causing problems. Rick, Emma, and Matt scolded Matt for modifying the timer without asking for their permission and Matt apologized to the group (Transcript, February 1, 2018). The group could not agree on how to improve the timer and this seemed to cause arguments and hurt feelings in a group that (according to my observations) usually said supportive and encouraging things to each other.

The group's discussion was dominated with talk of how their design worked. Transcripts from the 10 days of the design challenge included 781 coded utterances where a group member brought up issues in the function of the timer, shared and observation, or discussed a proposed modification. Yet, apart from the documentation of three time trials in a notebook and a few photographs the focal students did not engage with any reading or writing that could have helped them to collect data on the operation of their timer, despite the teachers encouragement to do so. After working in this way for several days, the group could not agree on the changes that they wanted to make. They became so confused that some of them started to think that something must have happened to the box outside of class. David suggested that the cardboard timer box was damaged overnight even though the boxes were stored safely in the room and photos of the box taken on successive days did not show any difference (Transcript, February 1, 2018). This could have been an opportunity for students to read and write to realize their solution— to use literacy to understand how their timer was working. They could have documented a series of time trials and read over their documentation to notice patterns in the data and agree on what changes they wanted to make to their prototype. If students had maintained their record of documentation and knew how to interpret it, they might have been able to see (and agree on) what changes they wanted to make in their design, but they did not seem to connect their notes on the three time trials to the problem they had understanding how their design worked.

Sketching the timer: Students struggle to create a useful sketch. In the four days before this design challenge, the students participated in a rapid prototyping activity that lasted three class periods. The students designed a bag for a partner’s needs and built prototypes in about 15 minutes with different materials that the teachers provided (e.g., cardboard boxes, plastic bags, and tape). Students created sketches in the rapid prototyping activity that proceeded this design challenge, but the sketches they drew were to convey their bag design idea to their partner, not to build a design using materials. During the rapid prototyping activity, the students did not need sketches to build their prototype. They worked directly with the materials provided (although sketching their idea likely helped them develop the idea for a bag). This was the same process the students ended up following with their cardboard timer even though on the first day of the design challenge the members of the team were divided in their approach. Emma wanted to work with the materials, cutting and arranging the ramps in the box without any sketching. Matt wanted to sketch the timer first and then use the sketch to construct the timer. David and Rick saw advantages to both approaches (Transcript, January 23, 2018). Matt's idea was to apply some of his mathematical knowledge to the design:

> No this is super easy math, guys. They're all just a bunch of right triangles. And then the height of the first one is the base...line of the, of every subsequent triangle. So we just have to measure how many centimeters we have to work with. (Transcript, January 23, 2018)

Encouraged by David and Rick, Matt worked on a sketch for the timer. (See Figure 7). The sketch included a rough outline of how Matt wanted to arrange the ramps, the dimensions of the cardboard box top, and a calculation of a right triangle (ramp).

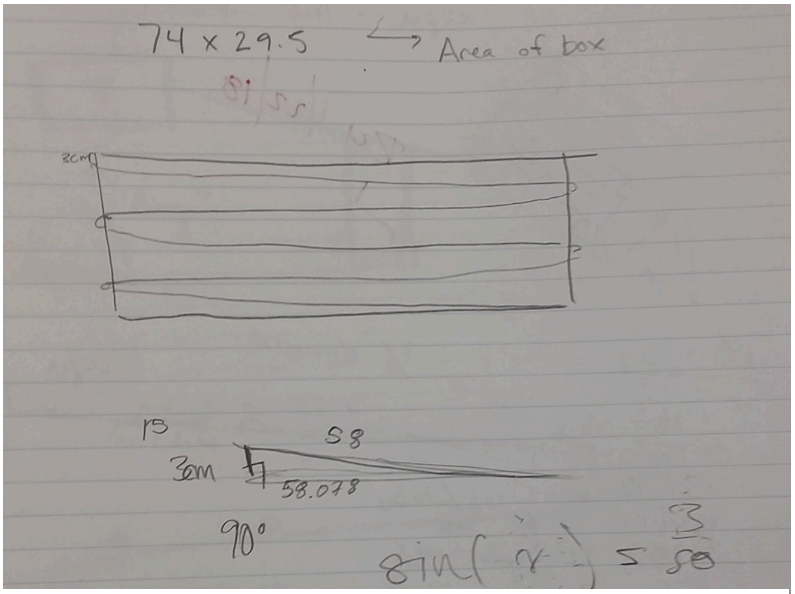


Figure 7. Matt's sketch of the cardboard timer

After Matt drew this sketch, he began drawing lines on the inside of the box, to correspond to the lines on his sketch. As Matt applied the lines to the box, he realized that he had forgotten to take the height of the ball into account. He adjusted the sketch, and then came back to the group with a new idea of how to position the ramps in the box:

> Okay so if you get a protract-, okay so basically you stick this thing here and you get a protractor and you angle it at 93 degrees and glue it down. That gets us so we can fit five of 'em [cardboard tube ramps] and they all have the same angle and there's three centimeters in between each one so that the balls won't roll against [the cardboard tube ramps]. (Transcript, January 23, 2018)

The group only had a meter stick to measure, so they could not draw lines on the bottom of the box top because the meter stick was too long and hung over the side of the box. The group also did not have a protractor, and they spent some time getting one from another classroom. Matt tried for the final time to apply his sketch to the box using the meter stick and protractor. He became frustrated working with the tools, the sketch, and the cardboard box, saying "This is so imprecise that it doesn't even... The calculations are actually useless." (Transcript, January 23, 2018). From this point forward, Matt (and the focal group) did not use (or refer to) a sketch. Instead, they worked directly with the materials, gluing ramps into the box and making additions as needed.

One issue that Matt mentioned aloud was that he wanted to fit five ramps in the box but from the sketch, he could not see a way to fit more than four unless they were at a very steep angle, which would make the ball roll too quickly. Later in the class, Matt spent some time manipulating the box and the cardboard tubes and found that he could fit in five ramps at an acceptable angle. Here, Emma's approach (stated above) to work directly with the materials worked for the group. In fact, the time that Matt and the other focal students spent manipulating the cardboard and glue might have helped them develop knowledge of the available prototyping materials. This might have been useful knowledge for further prototyping activities.

However, the focal students spent nine of the ten days of the design challenge positioning and re-positioning the ramps. The amount of glue and the tears in the box became an issue as clumps of glue or rough patches of cardboard made the ball roll inconsistently. If the students had a plan on paper, they might have avoided the damage that was caused by gluing and re-gluing the ramps. Furthermore, Matt wanted to make a sketch and felt frustrated when he could not do so. He was not able to engage in the design challenge in the way he wanted to.

Matt seemed to have the mathematical knowledge he needed to complete the sketch. He was able to see that the ramps and box created a series of right triangles. He knew how to measure and how to use a formula to calculate the sides of a right triangle. It appeared that Matt struggled to represent what he wanted to build on paper in a form that would support him to build and work with the materials at hand. With some help, Matt might have been able to finish his sketch. He would have needed to know what to measure and how to measure. He would have to know how to represent them on paper (including materials like the round cardboard tubes that the group used as ramps, which Matt represented in his sketch as a line). He would have needed the skill to design the timer with some unknown information; he might not have known exactly how long he wanted the ramps or exactly what angle he wanted, and he would have to develop the ability to solve these kinds of problems through sketching. If Matt were able to use a CAD program, he might be able to manipulate the different elements of the cardboard timer (instead of drawing multiple sketches or erasing and re-drawing). In short, if Matt had some knowledge of the kind of text he wanted to create (sketches or drawings used to construct an object) and if he had experience with that kind of sketching, this knowledge and skill might have supported him to create a usable sketch for the timer. The sketching that was a part of the rapid prototyping activity that proceeded the timer design challenge did not seem to impart this knowledge and sketching skill that Matt would have needed to create a usable sketch.

Here, Matt was attempting to realize his solution through the process of sketching. He could have sketched to understand more about the physical makeup (dimensions and material) of the design and how the design functioned (the angle of the ramps and how this affected the movement of the ball bearing). Through the sketch that he made, he learned something about the height of the ball bearing and the distance between the ball and the ramps, something that he did not notice or consider during his first sketch. Had he been able to engage in sketching in the way he would have liked, he also might have been able to use the sketch to develop a warrant for the design of his timer. He could have used the sketch as evidence that the timer would work efficiently. Reading and writing in this way might have enhanced the group's work with the timer because they might have been able to construct a better timer (or at least one with no tears in the cardboard or excessive amounts of hot glue) and they also might have understood more about how their design worked.

The solar car diagram: Students struggle to build using a diagram. In the eighth - grade science solar car design challenge, students measured a single solar cell's energy production at different distances from an overhead light (and at different angles). They then used this information to build a solar car using the same solar cell together with some cardboard, clay, a toy motor, and a set of toy wheels. Modeled after the solar car race of a nearby university, the goal of the design challenge was for students to design the fastest car that would move two meters down a table. For the solar car challenge, the four focal students (Ethan, Grady, Mia, and Olivia) were in separate groups. Ethan and Grady and one other student formed one group. Olivia worked with one of her friends, and Mia joined a group with three other students. There was only one document that students used during the solar car design challenge: the solar car design challenge handout (titled “Solar Car Design Criteria and Constraints”). This handout contained a description of the task, criteria for success, and a diagram of the solar car containing three figures to help students assemble the car. The design challenge lasted three days and all three groups containing focal students were able to get their cars to cross the finish line.

Ethan and Grady’s group tied with another group in the class for the fastest car, likely because they were able to get their solar car up and running early in the first class period of the design challenge, while Mia’s and Olivia’s groups got their cars to work on the third (and final) class period. Ethan and Grady’s speed gave them more time to try different design modifications such as modifying the position of the solar cell, deciding between one or two solar cells, and playing with the amount of clay to find what amount would make the car stable but add the least amount of weight (Fieldnotes, December 12, 2018). Both Mia’s and Olivia’s groups had trouble getting their cars to work by following the instructions in the handout. They spent much more time going back to the instructions trying to set up their solar car to match the one in the diagram. (See Figure 8.)

Both Olivia and Mia said they are working directly from the handout:

> Olivia: Um, we're just going with, like, we looked at um, the reading right here (*points to diagram*) and just kinda based it off of that, yeah.
> Mia: Basically it [the solar car] will look a lot like Dr. Meyer’s [from the diagram].
> (Transcript, December 11, 2017)

Olivia’s group had three main issues getting their car to work using the diagram. They placed clay over the wires, they did not align their gears so that the motor could spin, and they did not connect the wires correctly. Mia’s group also had trouble with placing clay over the wires and did not connect their wires correctly.

Olivia began by saying she was confused about the placement of the clay that held the motor to the cardboard saying “I don’t know if there’s clay [on the car]” (Transcript, December 11, 2017). The first time her group tested their car under the lights Olivia reported that they “accidentally put the clay [over the wires] and that’s why it wasn’t working” (Transcript, December 11, 2017). Later in class, Mia’s group tested their car and Dr. Meyers told Mia that the clay was covering the wires, but when Mia returned to her seat and looked at the diagram, she insisted that she had followed the diagram correctly:

> Dr. Meyers: So you see the wires over here. Why are they stuck into the clay, you guys?
> Mia: 'Cause I thought.... (*chuckling*)
> Dr. Meyers: So can you guys take a look at your directions. See if you're following your directions. See what the directions say.
> (*Students return to group table.)*
> Mia: (*looking at handout*) It should have worked that time!
> Student from Mia’s group: Yeah but you put the wires into the clay. I don't think that's gonna work.
> Mia: (*chuckling*) It should have worked that time.
> (Transcript, December 12, 2017)

In the diagram, tape holds the motor to the cardboard and not clay and there was a bullet point that instructed students to use clay in addition to tape. (The students did not have any tape, only clay). This might have confused the students, possibly because they did not have building experience necessary to build using the clay and the diagram did not give them this information. Mia’s insistence that the car should have worked even though she was told (by Dr. Meyers and a group member) that the wires were covered in clay might have been a joke. (She was chuckling at the time.) Or Mia might have been expressing her frustration because she believed she had built the car correctly according to the diagram.

Olivia and Mia’s group also struggled to get the wires connected properly. The diagram tells students to create a “closed circuit” according to the wire placement in the diagram. When Dr. Meyers asked Olivia’s group which wire on the solar cells was positive and which wire was negative, Olivia said “I dunno” (Transcript, December 12, 2017). Dr. Meyers helped Olivia and her partner figure out which wire was negative and which wire was positive:

> Dr. Meyers: Right. So if you look at these (*points to solar cells on table*). How do you know which one is positive and which one is negative? … Is it labeled in there?
> Olivia’s partner: Well, cause the black is like to the back [of the solar cell].
> Dr. Meyers: So what color does black represent usually?
> Olivia: Negative
> Dr. Meyers: There you go. So now you know how to do it, right?
> (Transcript, December 12, 2017)

The solar cells were not labeled with positive and negative, and neither was the diagram. Students had to understand how to build a “closed circuit” from the diagram, but the diagram alone was not sufficient because Dr. Meyers also had to coach the students to remember that black usually represented negative and point out where the black wire was on the solar cell. Olivia’s group needed this extra information to make sense of the diagram. Mia’s group had a different issue. They could not get the wires to join because there was not enough exposed wire to twist together. Dr. Meyers helped the group strip their wires with a stripping tool (Transcript, December 12, 2017). The students in Mia’s group did not recognize that they did not have enough exposed wire and this information was not in the diagram.

Only Olivia’s group had trouble placing the gears to connect the motor to the wheel axle. In the diagram, the placement of both gears is in the third picture and the bullet point next to the picture says that “the pinion gear rests on the larger flat gear.” When Olivia and her partner tested the car and it did not work, Dr. Meyers instructed them to “Go look at Figure 3 again. Clearly when you're having the two big gears together, it's not working right?” (Transcript, December 12, 2017). Mia came back a few minutes later and told Dr. Meyers that she had read the diagram and noticed “It’s [the gear is] like a little bit behind it” (Transcript, December 12, 2017). The picture might have looked like the large gear was behind the pinion gear, but the bullet point had said that the pinion rested on top of the larger gear. When Olivia and her partner test their car again, Dr. Meyers did not say they placed the gear incorrectly. He asks them about the noise he is hearing. “So when you hear that noise, that grounding noise, it usually means something is touching it. Is anything touching your gears?” (Transcript, December 12, 2017).

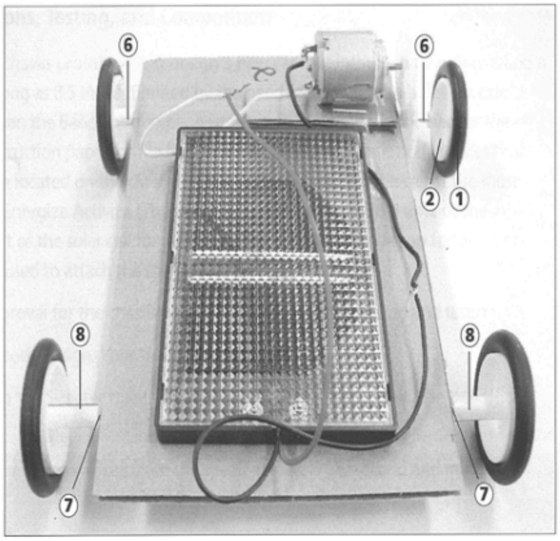
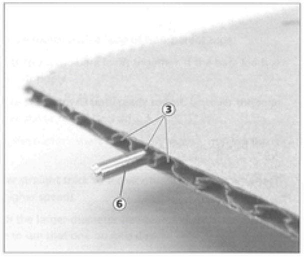
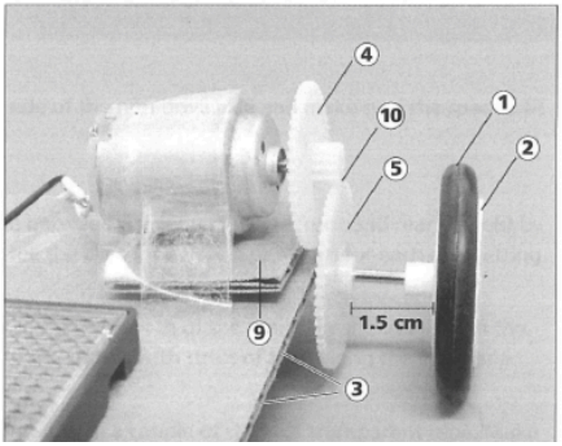
	**Figure 1 – Board Organization** • Set up a closed circuit for the cell and the electric motor as detailed in Figure 1. • Note the organization of the four wheels (Item #1 and #2) and the two axels (Item #6) in the cardboard base (Item #7). Use one cm straw spacers (Item #8) to help keep each wheel from moving laterally.
	**Figure 2 – Axle Placement Detail** • Note that the axel (Item #6) is placed in the cardboard holes (Item #3).
	**Figure 3 – Motor, Gear and Wheel Detail.** • Use clay in addition to tape to support the motor (Item #9) so that the gears are connected. • Be sure to situate the gears so that the smaller ‘pinion’ gear (Item #10) rests on the larger flat gear (Item #5).

Figure 8. Solar car diagram

Olivia had gotten the gears to mesh, but the diagram did not tell her to make sure that certain parts of the car did not touch the gears. Dr. Meyers gave Olivia this information as she was testing her car.

Grady and Ethan's group did not have the same trouble working with the diagram, but they also did not use the diagram very much. They looked at the diagram at least once during the design challenge but they did not fully know how to assemble the car. They did not know how to use the spacers or align the gears so that the axle of the wheel touched the gears that were connected to the motor. Ethan and Grady got their solar car to work by trial and error playing with the different pieces. They also got advice from Dr. Meyers that helped them arrange the spacers and gears (Transcript, December 11, 2017). In other words, Mia's and Olivia's groups spent more time with the diagram while Grady and Ethan's group went straight to building and testing.

The experience of constructing the solar car from a diagram could have been an opportunity for students to realize their solution. Instead of being given a functioning car to race and modify, students had the opportunity to learn about the different parts of the solar car by building it themselves. This knowledge of the solar car could have helped the students propose better modifications (modifications based on knowledge of the parts of the car and not on their own likes and dislikes). In this way, students could have used the diagram to build a more efficient car—to understand what design elements were important to consider when the goal was to build a faster car. However, Olivia and Mia seemed to struggle to build a car from a diagram. Perhaps students who had prior experience building from a diagram would have been able to build their solar car faster. However, this diagram was not one of the texts chosen to accompany the think-aloud interview protocol, and so I cannot say that the students reported any difference in their prior knowledge related to similar texts. However, it is reasonable to suggest that one reason that Grady and Ethan did not rely on the diagram as much as Olivia and Mia was that they already had experience building from a diagram. Grady and Ethan only needed to look at the diagram briefly to be able to construct the first iteration of their solar car, while Olivia and Mia spent days trying to make sense of the diagram and building materials to assemble them into a working car. This difference in the way the female students and male students worked with the diagram also suggests that there may be gender differences in students' prior experience that could cause differences in the way males and females complete the same reading and building activity.

Furthermore, the difference that Olivia saw in her ability to build the solar car and that of her classmates caused her to believe she was not very good at engineering (and possibly Mia as well, although she did not say so in her interviews). In their interviews, Mia and Olivia voiced their desire to study science and engineering in the future. (Mia wanted to become a surgeon and Olivia an engineer.) Yet, an interview a few days after the solar car design challenge Olivia talked negatively about her experience working with the diagram:

> Sometimes I feel like I'm not very great at it [engineering] because, like, there's some things for example like the solar car. I just did not understand it at all so I feel like I don't have the right mindset for it, but I will still like try to get better at it…So I feel like sometimes when we're doing, like building things, it will like come to me and I just know how to do it, even with the directions. But this time I was just looking at the parts and I was like "I don't know how this goes together" so I felt like I wasn't that great at doing the solar car. (Interview, December 11, 2017)

Olivia did not say she struggled to read in any of her other classes. She was reading 200 pages per week in her English class and she talked about how she enjoyed reading the Sunday newspaper (Interview, December 11, 2017). The struggle she had reading during the engineering design challenge was because she did not know how to read the diagram in ways that helped her build the solar car. In this quote, Olivia talks about “building things” as an important part of the work of engineering, and the ability to build (and build using directions) as part of “the right mindset” for engineering. Yet she does not seem to understand why she might be better at building some things than others. She attributes her difficulties to a lack of “the right mindset” instead of thinking that she has the background knowledge and reading skill to interpret directions in some situations but might not have the same knowledge and skill to build the gears and circuits of a solar car.

Conclusion: Difficulties to read and write to realize a solution. The purpose of reading and writing these “new” engineering texts during a design challenge was to realize the solution—to understand how a design worked and how it might be improved. Students could have documented their time trials to make decisions about how to improve the cardboard timer, sketched to plan their timer design, and built using a diagram to understand how the separate parts of a solar car functioned together.

Yet, students lacked the awareness of the need to use text to inform their design solutions and possibly also lacked the literacy knowledge and skill to work with text to support their planning, building, data collection, and evaluation around their design solutions. Students did not always understand that text could be used to solve an issue with a design (through documentation of time trials). If students did understand that text could be used to create and improve a design solution (through the sketching of the cardboard timer) they did not always have the knowledge or ability to create a text that they could use to achieve their purpose. If students understood that text could help them, and the text was given to them (such as a diagram of a solar car) they did not always have the knowledge or ability to read and work with the text.

Students who were strong readers and writers in other subject areas faced difficulty to read and write the texts of engineering.

The texts discussed in this chapter were new texts for students, but the question remains of how students engaged with text that was more familiar to them, texts they had worked with in other subject areas. In the following chapter, I will examine student engagement with these “school” texts and also examine both the affordances and constraints of the “school-like” tasks that set the parameters for student engagement with engineering reading and writing.

Chapter 5 Students Work with Familiar School Texts

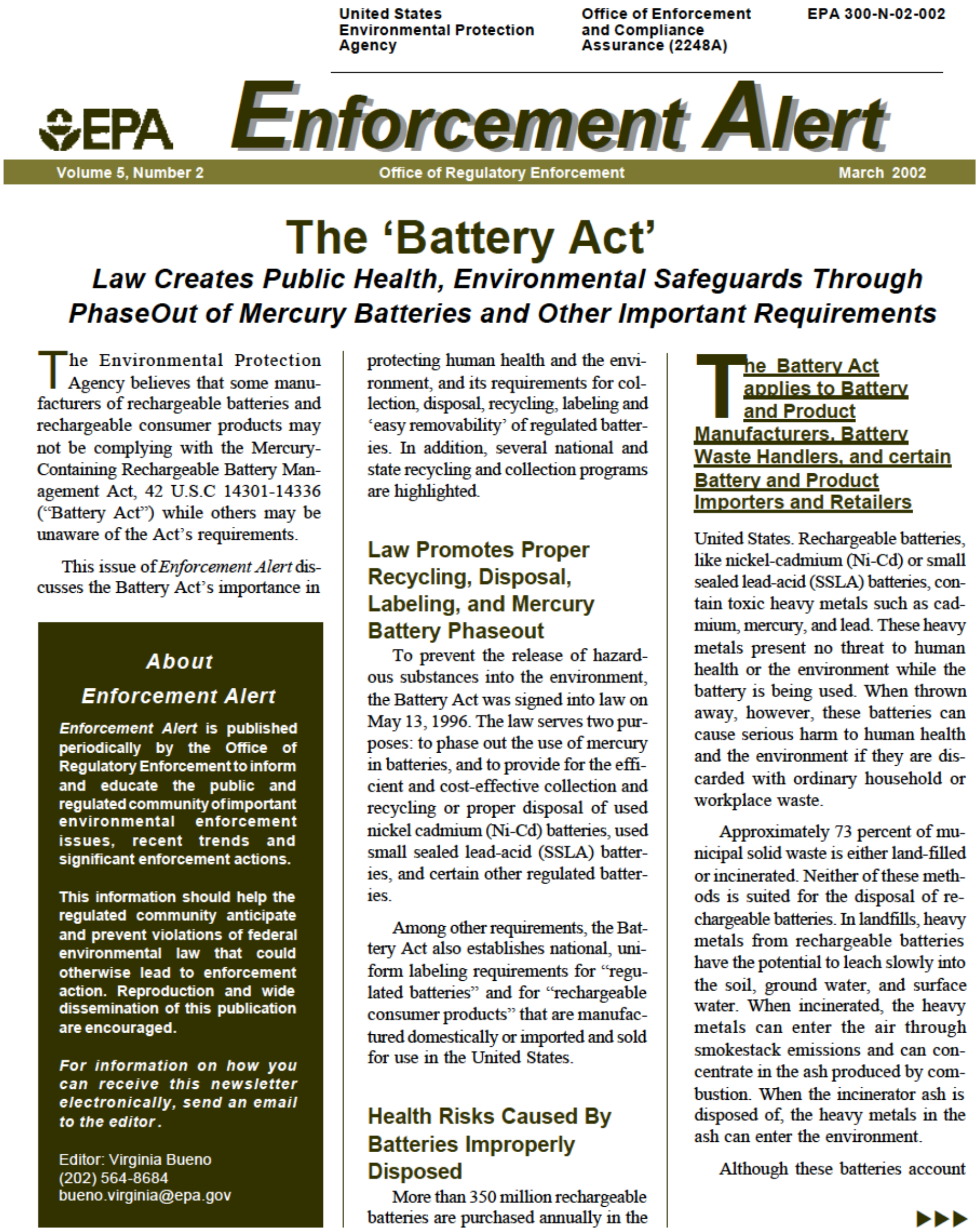
In this chapter, I examine student engagement with more common school texts, such as articles, that were a part of the engineering design challenges. I use two interactions with text to illustrate patterns I saw across the three classes in the use of familiar school texts. In the first interaction, students read an article with fluency and showed growth in their ability to comprehend the article over time. In the second, students comprehended the main idea of the text, an article abstract, but also expressed their struggle to make meaning of the text because of the density of new vocabulary. In both interactions, the students struggled to know how to use the information in the text in service of their engineering design projects. They read the text but did not use it as engineers would. They worked to comprehend the text but did not apply what they had learned to create or improve their designs.

First, I present and analyze the middle school students' engagement with one article about the 1996 Battery Act from the battery design challenge. Second, I present the high school students' engagement with one article abstract taken from a research article about titanium implants. Both analyses of literacy engagement with articles discuss students' comprehension using data from interviews before and after the design challenge as well as discuss the instructional activities around the two articles. The data show that both groups of students did not draw conclusions from the texts that influenced their decision-making during the design challenge. I conclude the chapter with a discussion of how the nature of the text and the constraints of the tasks (among other possible factors) might have kept students from engaging in engineering literacy practice (warranting, realizing, or delimiting a design solution) with these common school texts.

The "Battery Act" article: Comprehension without application. One document that students read in the eighth grade classroom during the battery design challenge was an article from the Environmental Protection Agency's "Enforcement Alert," a newsletter from the Office of Regulatory Enforcement. The article discussed the 1996 Battery Act, a law about the proper disposal of batteries. (See Figure 9.) Students read this article after they had created their own batteries in beakers, measured the voltage produced by different combinations of metals in their "beaker batteries," and recorded their results in a class data table. During the design challenge, students also participated in several whole-class and small group discussions about the data in the class data table, read about metals they had tested, and completed a report arguing for which battery would be best for a flashlight for campers.

Although students used the data table and readings about metals to argue for the "best" battery design for a flashlight, the work students did with the article on The Battery Act resembled a more traditional school assignment. Students read the article, answered comprehension questions, reviewed the questions in class, and then did not use the article for the remainder of the design challenge.

First and final think-aloud interviews show comprehension and fluency. Data from the think-aloud interviews showed that students grasped some of the main ideas of the article at the first reading. Students understood generally that improper disposal of batteries could have effects on human health and the environment. Ethan talked about the ill effects of improper disposal of metals, saying "when the metals are destroyed, they tend to go into the air and then you have to breathe them… it’s [the article is] trying to make sure that everybody knows the risks” (Interview, November 28, 2017). Ethan understood that certain metals in batteries were



United States
Environmental Protection
Agency

Office of Enforcement
and Compliance
Assurance (2248A)

EPA 300-N-02-002

EPA **Enforcement Alert**

Volume 5, Number 2 | Office of Regulatory Enforcement | March 2002

The ‘Battery Act’

Law Creates Public Health, Environmental Safeguards Through PhaseOut of Mercury Batteries and Other Important Requirements

The Environmental Protection Agency believes that some manufacturers of rechargeable batteries and rechargeable consumer products may not be complying with the Mercury-Containing Rechargeable Battery Management Act, 42 U.S.C 14301-14336 (“Battery Act”) while others may be unaware of the Act’s requirements.

This issue of *Enforcement Alert* discusses the Battery Act’s importance in protecting human health and the environment, and its requirements for collection, disposal, recycling, labeling and ‘easy removability’ of regulated batteries. In addition, several national and state recycling and collection programs are highlighted.

About

Enforcement Alert

Enforcement Alert **is published periodically by the Office of Regulatory Enforcement to inform and educate the public and regulated community of important environmental enforcement issues, recent trends and significant enforcement actions.**

This information should help the regulated community anticipate and prevent violations of federal environmental law that could otherwise lead to enforcement action. Reproduction and wide dissemination of this publication are encouraged.

For information on how you can receive this newsletter electronically, send an email to the editor.

Editor: Virginia Bueno
(202) 564-8684
bueno.virginia@epa.gov

Law Promotes Proper Recycling, Disposal, Labeling, and Mercury Battery Phaseout

To prevent the release of hazardous substances into the environment, the Battery Act was signed into law on May 13, 1996. The law serves two purposes: to phase out the use of mercury in batteries, and to provide for the efficient and cost-effective collection and recycling or proper disposal of used nickel cadmium (Ni-Cd) batteries, used small sealed lead-acid (SSLA) batteries, and certain other regulated batteries.

Among other requirements, the Battery Act also establishes national, uniform labeling requirements for “regulated batteries” and for “rechargeable consumer products” that are manufactured domestically or imported and sold for use in the United States.

Health Risks Caused By Batteries Improperly Disposed

More than 350 million rechargeable batteries are purchased annually in the United States. Rechargeable batteries, like nickel-cadmium (Ni-Cd) or small sealed lead-acid (SSLA) batteries, contain toxic heavy metals such as cadmium, mercury, and lead. These heavy metals present no threat to human health or the environment while the battery is being used. When thrown away, however, these batteries can cause serious harm to human health and the environment if they are discarded with ordinary household or workplace waste.

The Battery Act applies to Battery and Product Manufacturers, Battery Waste Handlers, and certain Battery and Product Importers and Retailers

Approximately 73 percent of municipal solid waste is either land-filled or incinerated. Neither of these methods is suited for the disposal of rechargeable batteries. In landfills, heavy metals from rechargeable batteries have the potential to leach slowly into the soil, ground water, and surface water. When incinerated, the heavy metals can enter the air through smokestack emissions and can concentrate in the ash produced by combustion. When the incinerator ash is disposed of, the heavy metals in the ash can enter the environment.

Although these batteries account

▶▶▶

Figure 9. Page 1 of the "Battery Act" article

harmful (“when the metals are destroyed…you have to breathe them”) and he understood that improper disposal of batteries was a “risk.” Similarly, Olivia discussed the disposal of batteries:

> You need to be careful how you dispose of these because it [the article] shows that clearly, like, they're trying to show through the facts and all they're explaining (November 27, 2017).

Olivia understood that there were harmful effects if the batteries were not disposed of properly ("you need to be careful how you dispose of these") and understood that the purpose of the article was to explain the risks of improper disposal ("they're trying to show through the facts… they're explaining").

Grady also understood that the purpose of the article was about disposing of batteries properly:

> This reading looks like a PSA about batteries and the importance of like how to deal with them to protect human health and the environment. (Interview, November 27, 2017).

Grady compared the article in "Enforcement Alert" to a Public Service Announcement (PSA) about batteries. Grady understood that batteries could be dangerous under certain conditions ("how to deal with them to protect human health and the environment").

Mia's summary of the article focused on the human health risks of improper battery disposal:

> If we stay with the battery act then people will have less chances of falling into seizures and comas but if we don't stick with it then there will be higher chances of the heavy metals spilling out and people getting sick (November 28, 2017).

Mia pointed out specific health effects ("falling into seizures and comas…people getting sick") and how the Battery Act prevented metals from contaminating the ground ("if we don't stick with it then there will be higher chances of the heavy metals spilling out").

In and out of class, the students worked with The Battery Act article through two activities. First, students read the article for homework and answered four comprehension questions (e.g. "List three of the heavy metals found in batteries," and "Describe when heavy metals are a threat to human health.") Then in class, students discussed their answers in groups for two and a half minutes and then as a class for three and a half minutes. Dr. Meyers guided the discussion by asking questions to help students understand the scientific content of the article. (In the discussion he also referred to a graphic depicting how heavy metals pollute the environment.) Below is the list of questions that Dr. Meyers asked during the discussion (in order):

> Why are they [heavy metals] a threat to human health?
> Why would incinerating this [a battery] be a problem?
> How would they [toxic chemicals] get in your lungs if you burned it [the battery]?
> Would it be a gas?
> What's going on with the gasses in the air? What can they do? What's the problem?
> What could they land in? What's a problems with our lakes and streams then?
> What could be some of the damages from these [heavy metals]?
> So what could be the outcome of this?
> (Transcript, December 1, 2017)

After a discussion of how toxins from heavy metals could pollute the water and pose a threat to humans who eat fish from polluted water, Dr. Meyers concluded the discussion by saying, "You could die. We could all die in terms of what's going on." Dr. Meyers asked questions for students to make meaning of the scientific content in the article and understand why this information was important. However, after these brief activities with the text, the students put the article aside and did not go back to it for the entirety of the design challenge. (One focal student did cite the article in the reference list of their final report, but I was unable to find any content in the body of the report that came from the article.)

These discussions might have helped the students show the deeper understanding of the article that was seen in their final think-aloud interviews. During the final reading, students were able to notice and explain aspects of the article that they had not noticed or understood before, and their responses show some of the ways they had drawn their own unique conclusions. For Olivia and Mia, a theme in their think-aloud interviews was their interest in human health and safety. In Mia’s final reading of the article, she made a prediction about how not following the battery act might affect human life, saying “things will just spiral downhill and we won’t have a place” (Interview, December 15, 2017). In Olivia’s final reading, she said:

> Last time I didn't notice this but this part right here talks about how they affect, like, how they can affect us and it says that they leach slowly into the soil and I realize that that can affect our water.” (December 11, 2017)

Olivia noticed the phrase “leach slowly into the soil” and said that this was the first time she had realized exactly how the metals would affect human health, that they could “affect our water.”

Ethan focused on the ways that batteries were disposed in the first reading of the article. It seemed that he was interested in how dangerous metals were destroyed. In his final interview, he said that batteries “are only really bad if they’re thrown out with ordinary household or workplace waste. I don’t know why that is” (November 28, 2017). He pointed out that he still did not understand how batteries thrown out in ordinary waste could be bad for the environment This differed from his first interview when he said that the only thing he did not understand were “the elements [e.g. mercury]… but I got the idea” (November 28, 2017), showing that he was able to more accurately point out what he did not understand in the second reading. A bit later in the interview, Ethan then answered his own question, showing that he understood how disposing of batteries in household waste could affect the environment, that toxic metals could “concentrate in the ash” if incinerated or “leach into the ground” (Interview, November 27, 2017).

Grady said in his interviews that he did not find the article interesting at all (“I don’t find this topic interesting”) and in his final interview he made a connection to the content of his favorite subject area, social studies, comparing the incident that started the Triangle Shirtwaist Factory Fire:

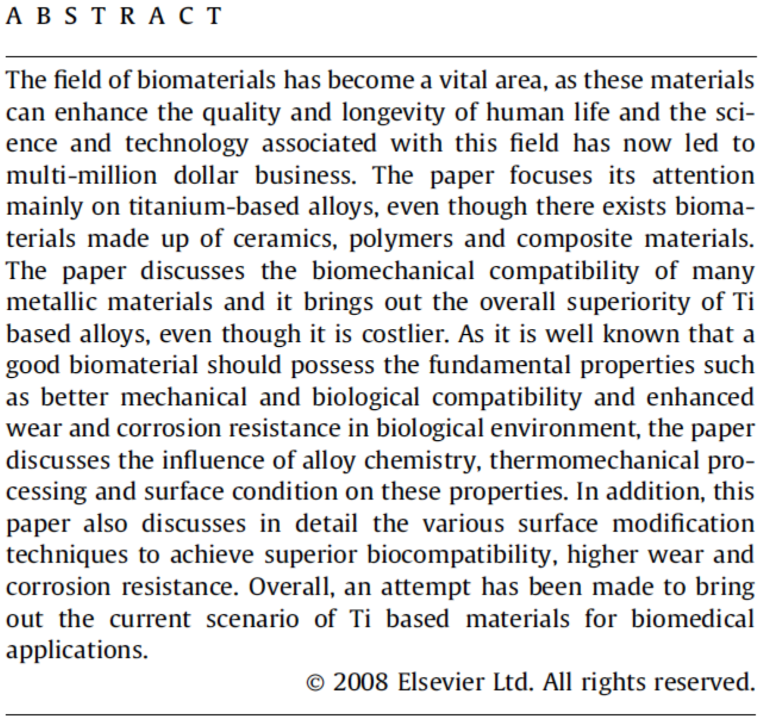
> That was all started because they [factory workers] put, like there was like lint in the trash can and they put a match in or something… and it started a fire… so that was like interesting because here you'd think you are just throwing it [a battery] away but it's having a really negative effect. (Interview, December 13, 2017)

Grady compared the factory fire and the damage it caused to the improper disposal of mercury batteries and the possible consequences for human life ("here you'd think you are just throwing it away but it's having a really negative effect"). In both cases, humans did not understand the consequences for a small act such as throwing away a match at a factory or throwing away a battery in household waste.

The students' think-aloud data from their final interviews showed that they were able to question the article and make connections. This gives some evidence that students could have applied conclusions from the article to make decisions about how to design a battery or what kind of battery to design if they had known why and how to do so. Here, students could have used the article in service of their battery design project to delimit the problem—to understand more about different kinds of batteries and the regulations that govern battery disposal. This information might have helped them decide what kind of battery to design. They also might have used this article to realize the solution— to understand more about the properties of different metals used in batteries. The students could have used this information to make design choices, to choose what metals they wanted to use in their battery. However, the students comprehended the article and engaged in activities around the article, but they did not apply information from the article to their design solution. In class, Dr. Meyers designed and led activities for students to comprehend the article but the students did not engage in activities to help them apply information from the article to their engineering design solutions. The students might not have worked with the Battery Act article as engineers might work with a similar document because the students did not apply the reading and writing to their engineering work.

The article abstract: A challenging text for students' comprehension and application. In the high school biomedical engineering class, Ella, Sofia, Meg, and Jenny completed a 11-day engineering design challenge to create a line of hip implants. They had to design and create prototypes for a cemented implant, an uncemented implant, a hybrid implant, and a reverse hybrid implant. Their hip implant solutions had to solve two design problems— to eliminate the use of bone cement, which wears off over time, and to eliminate or reduce the wear of polyethylene on the socket of the femoral head. The students also had to develop a prototype of the packaging for their line of hip implants that would preserve a sterile barrier between each part of the hip implant and the surrounding environment. Right before the first day of the design challenge, the students read an abstract and graph from an article about titanium implants, titled "Ti based biomaterials, the ultimate choice for orthopaedic implants – A review." (See Figure 10.) The students wrote notes, a biomaterials table, and sketches during the design challenge but the abstract was the only text the students had access to in class that they did not create themselves. Three of the four focal students discussed how vocabulary was a challenge when reading the article abstract (and in class in general) and although building a hip implant prototype helped students to grasp more of the concepts in the abstract the students did not use the abstract to improve their design solution. Students read and annotated the abstract and discussed it in class, and then did not use it again for the remainder of the design challenge.

Challenging vocabulary. In interviews Meg, Jenny, and Ella reported that they thought the vocabulary of the class was difficult. Sofia was the only focal participant who did not talk about the vocabulary being difficult. Sofia had arrived from Italy at the beginning of the school year and identified herself as someone who was still learning English (Interview, May 10, 2018). It is possible that she encountered new vocabulary in every class and so she did not find it



A B S T R A C T

The field of biomaterials has become a vital area, as these materials can enhance the quality and longevity of human life and the science and technology associated with this field has now led to multi-million dollar business. The paper focuses its attention mainly on titanium-based alloys, even though there exists biomaterials made up of ceramics, polymers and composite materials. The paper discusses the biomechanical compatibility of many metallic materials and it brings out the overall superiority of Ti based alloys, even though it is costlier. As it is well known that a good biomaterial should possess the fundamental properties such as better mechanical and biological compatibility and enhanced wear and corrosion resistance in biological environment, the paper discusses the influence of alloy chemistry, thermomechanical processing and surface condition on these properties. In addition, this paper also discusses in detail the various surface modification techniques to achieve superior biocompatibility, higher wear and corrosion resistance. Overall, an attempt has been made to bring out the current scenario of Ti based materials for biomedical applications.

© 2008 Elsevier Ltd. All rights reserved.

Figure 10. Abstract (Geetha, Singh, Asokamani & Gogia, 2009)

remarkable that she encountered new vocabulary in the biomedical engineering class as well.

The other three focal students did discuss the difficult vocabulary in the class and in class texts:

> After she [Ms. Walsh] explains it, obviously I understand it better and it helps me but, like, at first sometimes it's like big words and new words for me so I don't understand it as well (Jenny, Interview, May 5, 2010)
>
> 'Cause once again with the words it just frustrates me. It doesn't make me want to do engineering or do stuff for engineering (Meg, Interview, May 8, 2018)
>
> I tend to skim over things and I'm like "Uh... I've read it enough" and give up early… I guess just remembering which [bio]material is which [is difficult], because a lot of them have similar names and you're like "Uhhhhh.... I can't remember which one this is!" (Ella, Interview, May 9, 2018)

Jenny, Meg, and Ella were frustrated with the new vocabulary in the class and in the article abstract. As Jenny pointed out, they relied on Ms. Walsh to explain the new vocabulary to them ("after she explains it… I understand it better"). Jenny expressed a more positive attitude when she talked about challenging vocabulary, saying that she would come to "understand it better."

However, Ella talked about how she would “give up early” on reading before really understanding the text because there were so many new words (“a lot of them have similar names… I can’t remember which one this is!”). Meg also discussed the feeling of being overwhelmed by new vocabulary (“with the words it just frustrates me”) and how it made her not want to “do engineering.”

The first reading of the abstract. During the first reading of the abstract, the four students understood generally that titanium was biocompatible and therefore a preferred option for implants. Jenny said:

> The titanium seems like it’s the best option for implants and… why it’s compatible and…the corrosion, the wear and stuff, it’s like less than the other, like the other options it talks about (Interview, April 13, 2018)

Jenny understood that titanium was useful as a material used in an implant (“the best option for implants”) and also understood that it was “compatible” in the body because it was durable (“corrosion, the wear…less than the other options”). Similarly, Ella said the article was about:

> How titanium-based things, they tend to work with us but cost more money to use them. And there are cheaper ways to fix these things in the human body but titanium works better (Interview, April 12, 2018).

Ella also discussed biocompatibility of titanium implants (“titanium-based… tend to work with us”) and Ella explained another idea in the article abstract about how titanium was more expensive than other materials mentioned in the abstract (“there are cheaper ways.. but titanium works better”)

Meg and Sofia were also able to explain that titanium was biocompatible in their first reading. Sofia said, “It’s [the article is] about like the titanium dispositives. They are being studied and their compatibility with the human body” (Interview, April 12, 2018). Sofia understood the abstract was about titanium and that titanium was biocompatible (“titanium…compatibility with the human body”). Sofia also used a word “dispositives” when she explained the article, which possibly was a false cognate from Italian. The article discussed titanium alloys, so perhaps that was the word she was trying to use. Meg said the article was about “different ways for it [titanium] to be combat, compatible…trying to make it more of a thing for titanium-based materials to be applied into biomechanics” (Interview, April 13, 2018). Meg understood that titanium was compatible, but she did not say exactly what it was compatible with although later she mentions “biomechanics” giving some evidence that she meant titanium was compatible with the body. Meg thought the article was arguing for titanium (“to make it more of a thing for titanium-based materials to be applied”), showing that she understood titanium was a useful material.

The final read-aloud: Few shifts in comprehension. In class, students spent the majority of one class period (approximately 30 minutes) listening to Ms. Walsh explain the abstract, sentence-by-sentence. The students also annotated the abstract, following Ms. Walsh’s annotation on the overhead projector. Despite this work, in the final reading, it was difficult to see an obvious shift in student summaries of the article. The biocompatibility of titanium was theme in their responses as it was in the first reading of the abstract:

> It’s about biomaterials, specifically titanium…how biomaterials are used as a whole for things to make them more biocompatible. (Jenny, Interview, May 10, 2018)
> Just how titanium is used to impact different things, human life and other technologies as well and just the fact that all of these things, how resistant it is, how strong it is compared to other materials. (Ella, Interview, May 9, 2018).
> It’s about how different materials react with the body in particularly T-I based materials (Sofia, Interview, May 10, 2018)

In her summary of the article, Jenny pointed out that titanium is useful (“titanium… used as a whole for things to make them more biocompatible”). Ella talked about some specific properties of titanium (“how resistant it is, how strong it is compared to other materials”). Sofia said that the article was about how titanium interacted with the body ("materials react with the body… particularly T-I").

Meg's response showed that she still might be struggling to understand some of the main ideas of the abstract:

> Biomaterials have helped make life longer because metal would go into the blood so obviously people don't want metal in their blood so then using biomaterials has "enhanced the quality of long-e-tivity and human life." (Interview, May 8, 2018)

Meg understood that biomaterials could be engineered in ways that helped preserve the quality of human life ("have helped make life longer") and although the concept of metal corrosion was not a focus during the design challenge, Meg seemed to understand that metal could "go in the blood" if corroded. However, Meg did not seem to understand that titanium was both a metal and a biomaterial ("people don't want metal…. so then using biomaterials…") seeing biomaterials and metal as competing products, or possibly distinguishing between titanium as a metal that was more safe than other metals. Meg also read directly from the abstract instead of explaining in her own words ("enhanced the quality and longevity of human life"). She did this seven times in the interview. Most of her talk about the abstract included direct quotes that she did not explain in her own words.

The prompts of the think-aloud interview asked students to summarize the article and point out what they thought was important. The protocol did not focus in depth on measuring the students' understanding of the many new vocabulary words in the abstract. However, in the final reading of the article abstract, Jenny, Meg, and Ella still stumbled over some of the words. (Meg struggled to pronounce "enhance," "longevity," "alloy," and "polymer," while Jenny struggled to pronounce "superiority," and Ella struggled to pronounce "orthopedic.") It is possible that these words were just difficult to pronounce. It is also possible that the students were not exactly sure what these words meant. All four students read “Ti,” the symbol for titanium as a word, pronouncing it as “tai.” The students also read some words correctly but later said they did not understand what they meant, such as “thermomechanical” which was a challenge for all four students. The fact that there was little difference in the first and final reading of the abstract could have been because the students comprehended the main ideas and did not want to speak about anything beyond these main ideas. However, the students might still have been struggling with some of the new the vocabulary in their final reading even though they were able to grasp the main idea.

The final read-aloud: Improved understanding of materials. Even though the students might have struggled with vocabulary in the final reading of the article abstract, in the final interview all four students said that they understood the biomaterials (and vocabulary words that represented biomaterials) more than they had during the first reading. For these specific vocabulary words (e.g. “composites,” “polymers,” “titanium,” “ceramics”) students reported an increase in their understanding between the first and final reading. Meg said:

> Ceramics is like the plastics... and polymers... I forget what that one is. Composite is like all the things, like all the things mixed up together. A bunch of stuff together..... I still don't understand the ceramics and polymers but I understand the composite and titanium-based. (May 8, 2018)

Meg said she understood what composite and titanium was (“composite is like… things mixed up together”). She said she did not understand exactly what a polymer was (“don’t understand… polymers”). She seemed confused about ceramics, saying in the beginning that “ceramics is like the plastics” but then at the end of her response that she did not understand polymers. Her response gives evidence that the work she did during the design challenge helped her to understand what ceramics (and also possibly polymers) were, and she was able to articulate that she did not understand polymers, which she did not do during the first reading of the article.

Jenny, Ella, and Sofia mentioned the prototype specifically during their final read-aloud interviews. Jenny said:

> I just noticed that like before I didn't really understand what polymers and composites were. And now like it brings a picture to mind…"It discusses in detail the various surface modification techniques" That part is kind of interesting. Kind of what we're doing with the clay, drawing the design on it to show that it has a different surface on it. (May 10, 2018)

Jenny said that she envisioned polymers, composites, and surface modifications from her prototype and knew more about those materials than she did in the first reading ("before I didn't really understand… now it brings a picture to mind"). Jenny was able to visualize the materials in the prototype. She read about "surface modification" and remembered how she had manipulated the clay in her prototype on the cup of the hip implant by poking small holes into the clay to represent a surface modification ("kind of like what we're doing with the clay, drawing the design on it"). The first time Jenny read the abstract, she did not have a picture in mind for the biomaterials discussed in the abstract. The final time she read the abstract, she said she could visualize several materials ("polymers and composites…surface modification techniques").

> Ella also discussed the prototype when she read the abstract for the final time:
> I'm just thinking about the hip implant. We've been working on it for weeks… I'm still wondering why it has to be so costly to make them like that and to make them, to have that strength that titanium has versus the other materials that aren't as good, 'cause ceramics and polymers and composites are still used in them [titanium implants], they just use more titanium it seems than others, but still... why does it have to be so expensive? (May 9, 2018)

Ella said that she pictured the hip implant prototype after reading the first sentence of the abstract. She also was able to explain a relationship between the materials ("ceramics and polymers and composites are still used in them [titanium implants]") and after she discussed this relationship, she raised a question about a difference between the materials, why titanium was more expensive ("Why does it have to be so expensive?").

> Sofia talked about how familiar the text was because she was familiar with the prototype: The first time I read it [the article] I was looking at something that looks familiar but is not really familiar but now it's talking about a book that I heard about and talking about a book that I read. (May 10, 2018)

When I asked her for clarification about what she meant about "a book that I heard about" and "a book that I read." Sofia said, "when we had to prototype and go back to our notes and 'oh this is used, we can use this because it's better for this function'"(Interview, May 9, 2017). Sofia was picturing the process of working from the biomaterials table to create the hip implant prototype as she was reading (Interview, May 9, 2018). The article abstract looked like other articles that Sofia had read although the content was new ("I was looking at something that looks familiar but is not really familiar") and the process of building the prototype made the content in the abstract familiar ("talking about a book that I read").

Building the prototype helped students visualize some of the new vocabulary in the abstract. Rather than the article enhancing the students' work with the prototype, the opposite seemed to be true. Building the prototype helped students to learn about the biomaterials and when they saw these same biomaterials represented in the text of the abstract they were able to visualize their prototypes and understand the new vocabulary in greater detail. Additionally, Meg's interview presented some evidence that the prototyping also increased the students' confidence to work with new vocabulary. Meg said:

> I'm good at designing [the prototype] but I guess it depends on what it is and if I have to use certain materials or not... if I'm able to see the materials and use them but not when it's [the materials are] words, when it [the design criteria] says "Use this kind of material or that kind of material." (Interview, May 8, 2018)

Meg enjoyed working with the materials and found this work a more engaging way to build knowledge of the new vocabulary in the article abstract ("I'm good at designing… if I'm able to see the materials… not when it's words"). Meg was the only student in the focal group that was visibly off-task during parts of the design challenge. Meg texted on her phone during class (Fieldnotes, May 3, 2018). She took a five-minute nap wrapped in a blanket (Fieldnotes, May 7, 2018). She studied for an English test instead of helping the other students build the prototype (Fieldnotes, May 9, 2018). She did not speak more than a phrase or two during the day when they sketched their initial designs (Fieldnotes, May 1, 2018) but as soon as the students in her group started deciding which materials to use for the prototype, she began contributing to the group. Meg seemed to disengage from the parts of the class that involved working with new vocabulary and concepts that she did not understand. However, when the same vocabulary and concepts were discussed in terms of the prototype design, she became engaged in the group work, at times even leading portions of the work such as the design of the titanium femoral stem (Fieldnotes, May 2, 2018). For a student like Meg, working with the abstract might not have been a helpful way to learn vocabulary. She did not want to read. She wanted to prototype.

In short, prototyping supported the students' comprehension of vocabulary in the article abstract but the article did not seem to give students information that they could use to create a hip implant design. The students in class only read the abstract one time in class for one activity and (based on my fieldnotes) the focal students never used it again. The students might have used this text to delimit the problem, to learn more about hip implants and make a decision about what kind of hip implant to design. Or the students might have used the text to realize their solution, to learn more about the properties of titanium and to warrant their design solution by gathering textual evidence to support the use of titanium in their hip implant design.

However, it is also possible that the students did not use information in the text to create a hip implant because they did not find the article to be useful for that purpose. The article abstract might not have contained information that helped students to delimit a problem, realize a solution, or warrant their design. It seemed to be a challenging text for students to work with due to the high density of new vocabulary so the abstract might have been too difficult for students to work with. Also, the abstract was only a summary of the full article so it might not have had enough information for students to use. As they read the article abstract, students were reading a text that engineers might use but they reported feeling frustrated with the vocabulary, and they did not use information from the article in their hip implant designs.

Patterns with Traditional School Texts Across the Classrooms

With the exception of the solar car challenge, each design challenge across the three classrooms included at least one article (or article abstract). The pattern in the data was that the design challenges included only one article (except for the battery design challenge where students also read about metals), but the one article was a central text in the curriculum.[4]

When I asked Ms. Walsh about the texts that were important in the design challenge, she said:

> There's not a textbook for this. Because there's nothing for it, there's nothing I can use for it. Anything that does exist is too overwhelming…but other than the abstract, the articles are the things we'll use (Interview, April 9, 2018).

Ms. Walsh found it difficult to find appropriate text ("not a textbook…anything that does exist is too overwhelming") but she had found the article about titanium implants ("the abstract"), and this became a focal point in addition to several online articles students read about biomaterials

---

[4] The students in the high school engineering design course also discussed an article about the design of the Aeron chair in class for seven minutes and then were assigned the article for homework (Transcript, February 23, 2018).

very early in the unit, several weeks before the design challenge ("the articles… the things we'll use"). Dr. Meyers spoke about the importance of engaging students using primary source documents such as the Battery Act article:

> I kind of knew what texts I wanted [for the units]. I have thought about how to use primary sources to support things. That's something I've been working on for 10-15 years... things [documents] you would see if you had a job [as an engineer] (Interview, December 18, 2018).

For Dr. Meyers, it was important that students read documents that engineers would read ("things you would see if you had a job"). This belief and his experience ("something I've been working on for 10-15 years") guided him as he chose texts for the class ("I kind of knew what texts I wanted… primary sources").

Across the three classrooms students did not read many articles, but the teachers believed that engagement with the articles was an important activity in their units. (I do not have any interview or observational data that show that the students believed reading the articles was a central activity compared to the other reading and writing in class.) Both Ms. Walsh and Dr. Meyers chose texts from engineering publications and Dr. Meyers pointed out that he chose these "primary texts" to give students the experience of engaging with texts that engineers would actually use. However, the students in both classes did not read the engineering texts for the same purpose as an engineer would—to create or improve their design solutions. This suggests (1) that students needed more support to know how to use the articles and/or (2) the texts themselves, though they were authentic engineering texts, might not have been useful for the purposes of the design challenge.

Conclusion: Reading and writing school text to develop an engineering solution

The purpose of reading and writing familiar school texts, such as articles, in the three engineering classrooms was unclear because students only comprehended the articles and did not apply the reading. Both the middle school science class and the high school bioengineering class needed some instructional support to comprehend the article, although the middle school students did not talk about how vocabulary was a challenge for them in the way that students in the high school class did. The focal students in both classes read these articles and learned some general information about a topic related to their design. However, none of the focal students used familiar school texts (such as articles and abstracts) as engineers and the instructional tasks of both classrooms only supported students to comprehend, and not to apply text to their work as engineers would.

This chapter presented work around an article and an article abstract but every design challenge included a range of texts. How did students engage in engineering literacy across the wide range of genres and modes of text to create and improve their design solutions? In the final findings chapter, Chapter 6, I will discuss the nature of students' engagement as they read across multiple texts during the design challenge and explain how students read and wrote to warrant a design solution.

Chapter 6 Reading Across Text to Warrant a Design

In this chapter, I present findings on how students read across multiple texts to warrant their design solutions. I present three exemplars in this chapter to illustrate the work that students did to read and write across text to make design choices and warrant their design solutions. I use the data to illustrate how students read and wrote across new and familiar text to gather evidence that their design worked to fill a user need. As students read and wrote across text for a new purpose, to warrant a design, they faced the same challenges with new and familiar school text as illustrated in Chapters 4 and 5. The three exemplar data I present in this chapter show both the successes and challenges students faced to read according to this purpose. Furthermore, I use the data to argue that students needed both supportive texts and tasks to engage in warranting their designs— supportive texts contained information that students needed to warrant their designs and supportive tasks provided guidance to engage in using both "new" engineering texts and familiar school texts for engineering purposes (warranting, delimiting, and realizing).

In the first example from the eighth grade battery design challenge, students created and read a data table, read non-fiction excerpts about different metals (and took notes on the reading), and wrote final reports. The texts contained information that was useful for warranting the design of the battery and through engagement with the instructional tasks, students developed warrants for the design of a battery for a camping flashlight based on textual evidence. In the second example from the high school engineering design class, students created and read a data table with body measurements and read and wrote interview notes. The texts contained information that was useful for warranting the design of a stool, but the students struggled to use the text to develop warrants using textual information as they participated in the tasks of the design challenge because they did not seem to know how to use familiar text (a data table) and new texts (user interviews) for engineering purposes. In the third example from the high school biomedical engineering design class, students sketched their designs for hip implants and read a table with information about different biomaterials. The texts did not contain all the information students needed to warrant their designs, and so the students were not able to present strong arguments for their design of a hip implant after participating in the tasks of the design challenge.

Reading and Writing to Warrant a Battery Design: Supportive Texts and Tasks

During the battery design challenge, students in the middle school science classroom designed a battery for a flashlight for children at a summer camp. During the design challenge, students read and wrote two focal documents: a data table that the students built collaboratively, and a packet of several non-fiction excerpts about the metals they had tested. As they engaged with these documents, the focal students developed arguments for the design of the battery based on which batteries would be safe (non-toxic) and produce enough voltage.

The students engaged in several activities with the data table and metals readings. (See Table 7.) They created the data table together and discussed patterns in the table as a class. They read the metal readings in small groups and discussed what metals would be safe. When the students were first introduced to the design challenge, they were confused about the criteria for determining the best battery. The following is an excerpt from their conversation:

> Dr. Meyers: How might we define “best”? What does it mean for this design challenge?
> Grady: ... good for the environment
> Mia: It's not gonna... it's good to put on the ground without polluting
> Grady: Approved by Grady... and won a J.D. Power Award.
> Ethan: It doesn't spread. It doesn't react to the ground.

> Grady: Receives an 89 on "Rotten Tomatoes."
> Mia: I thought Rotten Tomatoes was .... aren't they bad
> Olivia: Yeah
> Grady: They rate movies.
> (Transcript, November 30, 2017)

The students had a general idea of what kind of battery they wanted to make ("good for the environment," "put on the ground without polluting," "It doesn't react to the ground."), but the students did not refer to the table they had created even though it was on the whiteboard in front of them and they each had a paper copy. They also did not discuss any of the metals they had been working with for the last few days.

Table 7: Activities around the Data Table and Metal Readings During the Battery Design Challenge

Date	**Activity**	**Time Spent on Activity**	**Text(s) Used**
11/30/2017	Students discuss how they define "best battery."	2.5 mins	Instructions for design challenge
11/30/2017	Students make and test metals in "beaker batteries" and record voltage in a class table.	26 mins	Data table
12/1/2017	Students discuss the results of the class data table.	5 mins	Data table
12/1/2017	Small group discussion and note-taking: ranking batteries #1-5 based on voltage and safety of metals	7.5 mins	Data table, metal readings, students' composition books
12/4/2017	Review: Students discuss data table and refer to metal readings and share their top 5 batteries in small groups.	10.5 minutes	Data table, students refer to metal readings but do not have the document
12/4/2017	Students critique examples of reports (conclusions and rebuttals).	12 minutes	Sample conclusions and rebuttals
12/4/2017	Students discuss first draft of their reports in class with a partner. (They finish the reports for homework.)	3 minutes	Student reports, data table (on whiteboard)

After this small group discussion, Dr. Meyers led two full-class discussions of the data table at the end of class on November 30th and the beginning of class on December 1st. (See

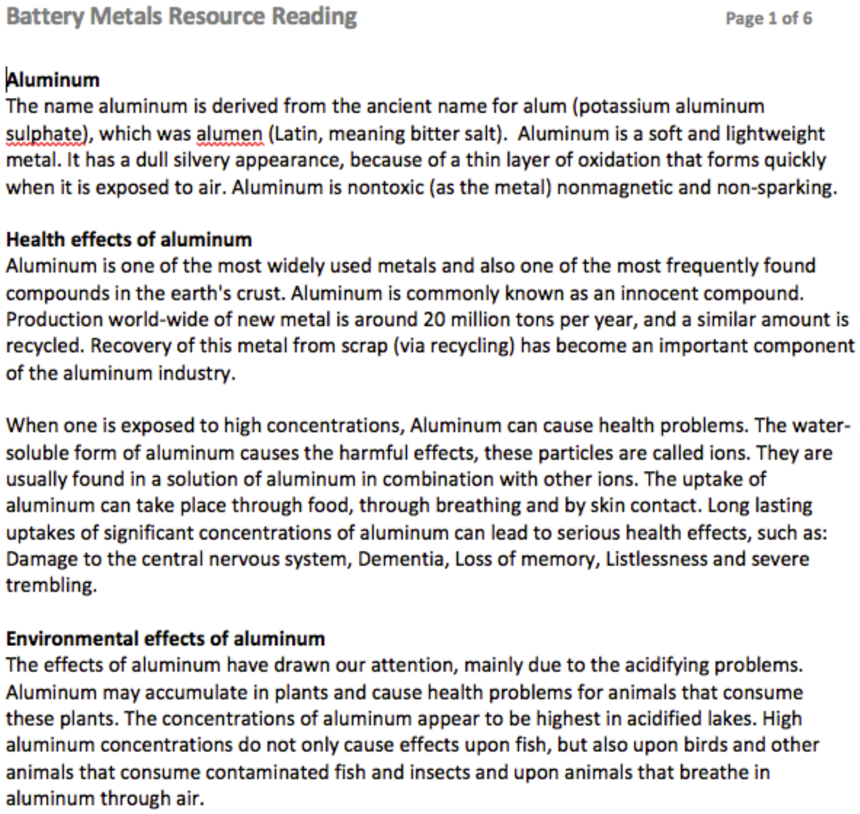
Table 7.) Dr. Meyers asked students what they noticed in the table and brought out patterns that the class was seeing in the data:

> Dr. Meyers: The type of substance influences the kind of chemical energy it has. Do we have any evidence? *(Turns around and looks at the data table on the whiteboard.)* Do we have any evidence that the type of metal it is influences the type of energy it has? …
>
> Ethan: Yeah because anything with the magnesium compound has over 1 average most of the time.
>
> Dr. Meyers: Ah so you're saying it seems like things with magnesium seem to be higher than others.
>
> Student 1: So like the metals we tested. Both of them, they all had different voltages.
>
> Dr. Meyers So you tested different metals and they had different voltages, right? Ethan?
>
> Ethan: So if you use the same metal for both of them, it doesn't have high voltage.
>
> Dr. Meyers : Oh so when we use the same metal, it doesn't seem to have a high voltage but when we use different metals, we clearly get a higher voltage. Would you agree with that? Okay awesome.
>
> (Transcript, December 1, 2017)

Dr. Meyers read this table with knowledge of scientific principles ("The type of substance influences the kind of chemical energy it has") and noticed patterns in the data based on his scientific knowledge ("When we use different metals, we clearly get a higher voltage"). In this excerpt, he worked with the students, modeling his own reading and leading students to notice what he had noticed. He took students' observations and related them back to scientific principles. He was teaching students how to read a data table like a scientist or engineer might read the data.

In the activities that followed this class discussion, students received more support to read the table as battery designers. They worked in small groups to rank the batteries in terms of their power using the data table. Then they read and discussed a packet of readings about each metal they had tested. The packet consisted of excerpts taken from the Lenntech company website, a company specializing in water treatment solutions. (See Figure 11.) The students used the metal readings to rank the batteries according to their environmental impact.

During this guided practice, the students began to draw conclusions from the data table and metal readings that could help them design a battery. In the students' discussion notes, they ranked the batteries by voltage. Then they ranked the metals by how safe they were for humans and the environment. (See Figure 12.) Students wrote notes by each of the metals they had ranked, noting things like "toxic fumes with air" and "terrible for environment." Students discussed their rankings in small groups and then wrote individual reports for homework.



Battery Metals Resource Reading Page 1 of 6

Aluminum
The name aluminum is derived from the ancient name for alum (potassium aluminum sulphate), which was alumen (Latin, meaning bitter salt). Aluminum is a soft and lightweight metal. It has a dull silvery appearance, because of a thin layer of oxidation that forms quickly when it is exposed to air. Aluminum is nontoxic (as the metal) nonmagnetic and non-sparking.

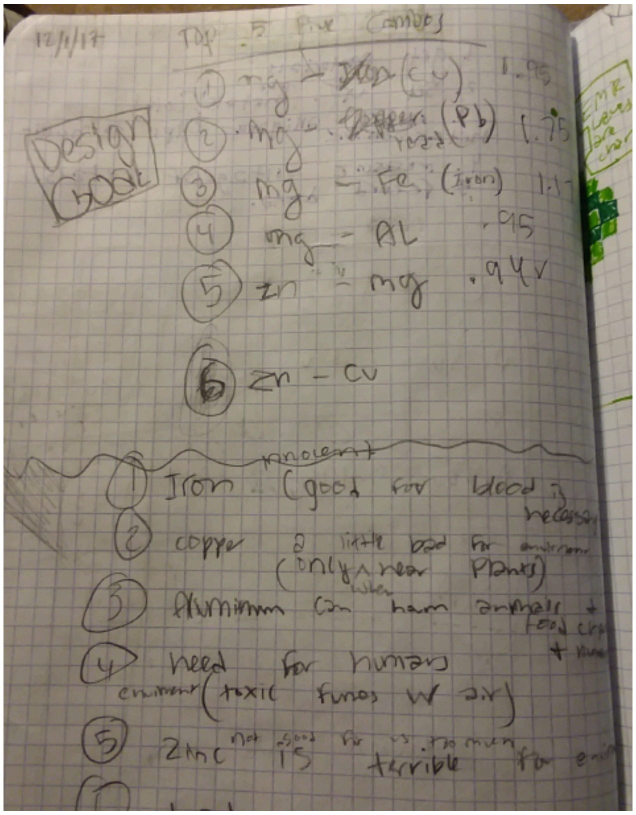
Health effects of aluminum
Aluminum is one of the most widely used metals and also one of the most frequently found compounds in the earth's crust. Aluminum is commonly known as an innocent compound. Production world-wide of new metal is around 20 million tons per year, and a similar amount is recycled. Recovery of this metal from scrap (via recycling) has become an important component of the aluminum industry.

When one is exposed to high concentrations, Aluminum can cause health problems. The water-soluble form of aluminum causes the harmful effects, these particles are called ions. They are usually found in a solution of aluminum in combination with other ions. The uptake of aluminum can take place through food, through breathing and by skin contact. Long lasting uptakes of significant concentrations of aluminum can lead to serious health effects, such as: Damage to the central nervous system, Dementia, Loss of memory, Listlessness and severe trembling.

Environmental effects of aluminum
The effects of aluminum have drawn our attention, mainly due to the acidifying problems. Aluminum may accumulate in plants and cause health problems for animals that consume these plants. The concentrations of aluminum appear to be highest in acidified lakes. High aluminum concentrations do not only cause effects upon fish, but also upon birds and other animals that consume contaminated fish and insects and upon animals that breathe in aluminum through air.

Figure 11. Excerpt from packet of metal readings

In their final reports, each student explained why their top choice of battery was the "best" based on voltage and the properties of the metals. (See Figure 13.) Ethan argued that the Al-Cu battery was the best, Mia and Oliva chose the Mg-Fe battery, and Grady chose the Cu-Fe battery. Each student specified the voltage: Mia gave the voltage in a table only, while the other three students included the voltage in a table and in their "conclusions" paragraph.



12/1/17 Top 5 Five Combos

Design Goal

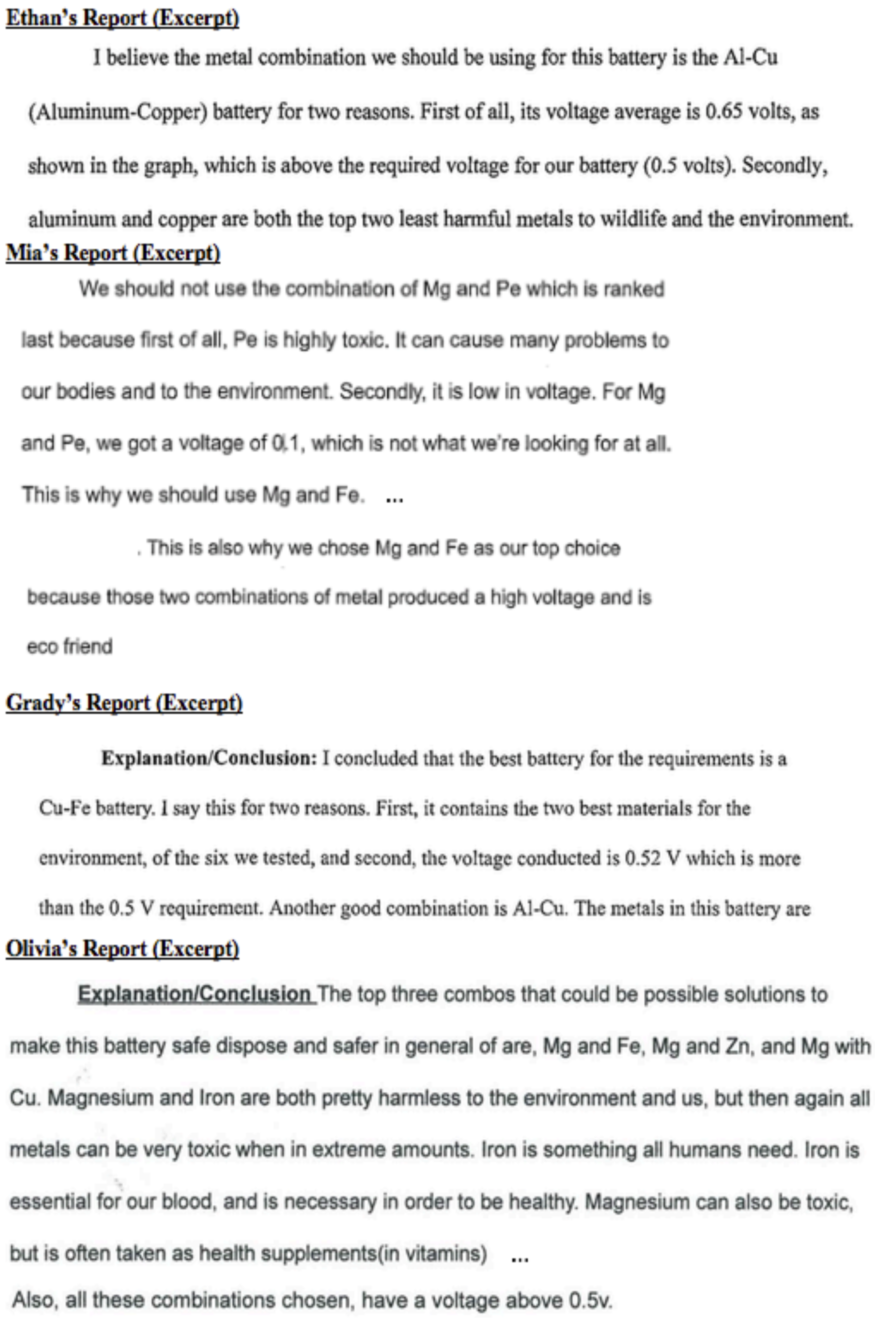
① mg – ~~Iron~~ (Cu) 1.95
② mg – ~~[illegible]~~ (Pb) 1.75
③ mg – Fe (iron) 1.17
④ mg – AL .95
⑤ zn – mg .94v
⑥ zn – cu

innocent
① Iron (good for blood is necessary
② copper a little bad for environment (only when near plants)
③ Aluminum can harm animals + food ch + hum
④ need for humans environment (toxic fumes w/ air)
⑤ Zinc is not good for us too much terrible for en

EMR Levels are

Figure 12: Olivia's notes, metal combinations and metal ratings

Each student also discussed the properties of the metals. Olivia discussed specific properties of iron in the "conclusions" paragraph, that iron "is essential for our blood and necessary in order to be healthy." The other three students included that information in the body of the report. Mia discussed how "Fe is good for ur bodies but if we take too much Fe, then we could die." Ethan did not include specific information about why aluminum and copper were "least harmful," but he did explain why magnesium was harmful, saying "when discarded to landfills or other outdoor piles, the toxic chemicals can leech into the ground." Grady included a chart with a sentence about each metal in his top five batteries earlier in his report. For example, for aluminum he wrote “Animals can have health problems if there is aluminum in the air, water, plants, or if they eat another animal that contains aluminum.”



Ethan’s Report (Excerpt)

I believe the metal combination we should be using for this battery is the Al-Cu (Aluminum-Copper) battery for two reasons. First of all, its voltage average is 0.65 volts, as shown in the graph, which is above the required voltage for our battery (0.5 volts). Secondly, aluminum and copper are both the top two least harmful metals to wildlife and the environment.

Mia’s Report (Excerpt)

We should not use the combination of Mg and Pe which is ranked last because first of all, Pe is highly toxic. It can cause many problems to our bodies and to the environment. Secondly, it is low in voltage. For Mg and Pe, we got a voltage of 0.1, which is not what we’re looking for at all. This is why we should use Mg and Fe. ...

. This is also why we chose Mg and Fe as our top choice because those two combinations of metal produced a high voltage and is eco friend

Grady’s Report (Excerpt)

Explanation/Conclusion: I concluded that the best battery for the requirements is a Cu-Fe battery. I say this for two reasons. First, it contains the two best materials for the environment, of the six we tested, and second, the voltage conducted is 0.52 V which is more than the 0.5 V requirement. Another good combination is Al-Cu. The metals in this battery are

Olivia’s Report (Excerpt)

Explanation/Conclusion The top three combos that could be possible solutions to make this battery safe dispose and safer in general of are, Mg and Fe, Mg and Zn, and Mg with Cu. Magnesium and Iron are both pretty harmless to the environment and us, but then again all metals can be very toxic when in extreme amounts. Iron is something all humans need. Iron is essential for our blood, and is necessary in order to be healthy. Magnesium can also be toxic, but is often taken as health supplements(in vitamins) ...

Also, all these combinations chosen, have a voltage above 0.5v.

Figure 13: Excerpts from students' final reports

Using the data table and metals readings and engaging with the instructional activities around the texts, students began the design challenge by arguing that a battery was “best” because it was generally good for the environment (or won an award) and, over the course of the unit, were able to warrant that their battery was the best based on textual evidence that the battery worked (produced adequate voltage) and would be safe for campers to use (did not contain harmful materials). The data table and metals readings contained information that students used to decide what combination of metals would produce enough voltage and not harm humans or the environment. The tasks of guided whole-class discussion, small-group discussion to rank the batteries, and report writing supported students to engage with these texts to warrant their designs. Students engaged with text to warrant a design solution and the texts and tasks supported students to read and write as engineers would, to build evidence that their battery design worked for a specific purpose.

Students Struggled to Use Text to Warrant their Stool Design

During the "Stool of Best Fit" design challenge in the high school engineering design course, students designed a stool for members of the school's robotics team. Students had to learn about the team and choose a sub-group of users for their stool design. Dr. Meyers instructed students to collect and interpret a range of data including measurements of the members of the robotics team, photos and videos of robotics competitions, and interviews with members of the robotics team during the 12 class periods that Dr. Meyers spent preparing students for the design challenge (See Table 8). The class discussed a reading on the development of the Aeron ® chair, they constructed a table containing the measurements of robotics team members, Dr. Meyers spent three days teaching students techniques for interviewing and observation, and right before the design challenge the students took three days to design a wooden gear using CAD software. After this initial instruction, the students worked independently in groups for six class periods to design their stools.

On the sixth day, the focal group presented their initial designs to the class using a cardboard prototype of a stool. The focal group designed the stool to hold snacks and called their design a "snack box." There were two central texts that students used during the design challenge: notes from interviews of robotics team members and a data table containing body measurements from the robotics team members.

Table 8. Texts Used During the "Stool of Best Fit" Unit

Preparation for Design Challenge (12 class periods)

Main Activities	**Texts Provided***
- Students discuss the design brief - Students hear presentation from class visitor (a professional engineer and professor) - Students hear presentation with information on interviewing and observing - Students discuss three photos of the robotics team and note observations - Students design a wooden gear using CAD software and cut out the gear using a CNC machine - Lecture and discussion (of PowerPoint)	- Article "The Athropometrics of Fit" (about the design of the Aeron chair) - Handout: instructions for taking measurements, questions for analyzing measurement table - PowerPoint presentation (containing 1 graphic representation of the design process, and "how to" information for 4 techniques: moccasin walker, process mapper, anthropologist, interviewer) - Handout: 3 photos of robotics team - PowerPoint presentation (CNC carving skills, copy of design criteria)

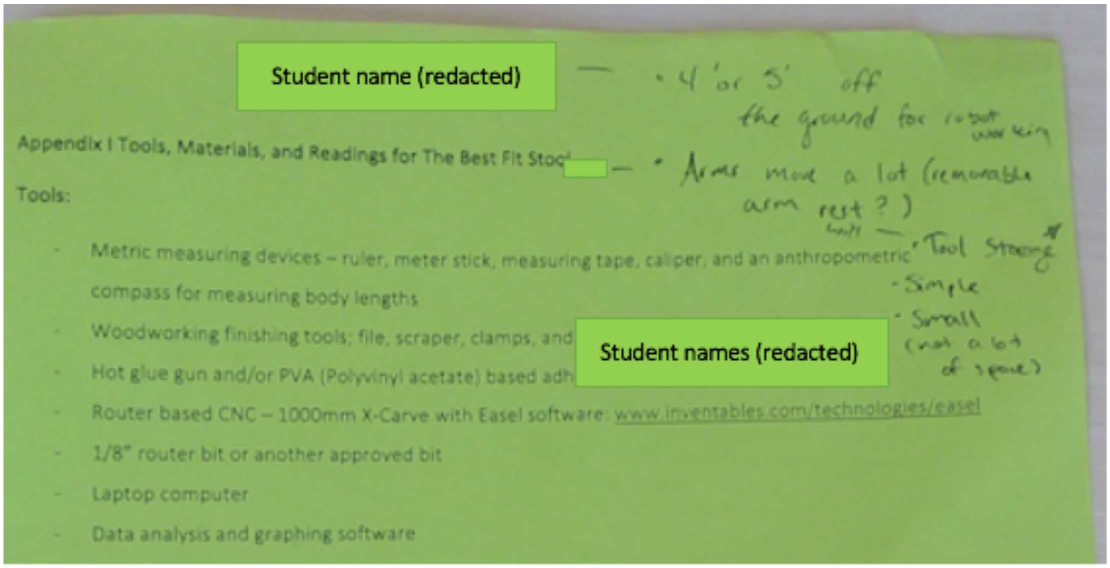
Design Challenge (6 class periods)

Objective	**Texts provided**
How might we design a stool that is the best "fit" for members of Fairview's Robotics team when they are at a Robotics competition? (design brief)	- Design brief - Photos and videos of robotics competitions - Table of measurements taken of robotics team members

Note. Table does not include texts assigned for homework or suggested texts for extra reading.
Note. I observed the first week of the design challenge when students created their initial designs, not the full unit.

Reading interview data to understand user need. The students in the focal group conducted one interview with three members of the robotics team. The focal group's interview lasted 4 minutes and 10 seconds. David took notes on the corner of his design brief. (See Figure 14.) Dr. Meyers had spent three days discussing techniques for interviewing and recording observations (February 27, February 28, March 1, 2018), but David only recorded a few interview notes in the corner of his handout. (These notes were the same notes I discussed in

Chapter 4.) In his notes, David recorded the person he interviewed and wrote down a few words about what they said (“simple, arm rest, small”). He marked one piece of information with a star and he also recorded his own design ideas related to the information (removable arm rest?). Writing notes was a way for David to record the information for further use. David also used his notes to process information, annotating his notes with a star and writing down design ideas. The group did not interview any other robotics team members during the design challenge.



Student name (redacted) — • 4' or 5' off the ground for robot working

Appendix I Tools, Materials, and Readings for The Best Fit Stoo[redacted] — • Arms move a lot (removable arm rest ?)

Tools:

- Metric measuring devices – ruler, meter stick, measuring tape, caliper, and an anthropometric compass for measuring body lengths
- Woodworking finishing tools; file, scraper, clamps, and
- Hot glue gun and/or PVA (Polyvinyl acetate) based adh
- Router based CNC – 1000mm X-Carve with Easel software: www.inventables.com/technologies/easel
- 1/8” router bit or another approved bit
- Laptop computer
- Data analysis and graphing software

Student names (redacted) with — • Tool Strong *
• Simple
• Small (not a lot of space)

Figure 15: Interview notes from stool design projects

The day before the group presented their prototype to the class David said:

> I'm worried about everything. I think that I was reading about the specific group we're serving, I think is kind of a problem for us because we don’t… like it's sort of for the people who repair the robot, it's also for people who sit in the stands, it's also sort of... and I'm a little worried that if we try to serve a bunch of people we'll end up serving no one (Interview, March 20, 2018).

At the end of the first week of the design challenge, David worried that the team did not know who they were designing for (“if we try to serve a bunch of people, we’ll end up serving no one”). David took interview data and he read over this data and also used it to create a poster presentation for the class (“I was reading about the specific group we’re serving”), and he had an idea of two groups of people that could use a stool ("the people who repair the robot…sit in the stands"), but he did not use the interview data to build a case that one of these groups should be the target user for his group's design. Instead, the group proceeded to design the stool for multiple groups of users but this caused anxiety for David ("I'm worried about everything") because he believed if the stool was not designed with a specific group in mind, it would not serve any group of users ("we'll end up serving no one").

Reading measurement data to design a stool. Before the group decided on their "snack box" idea for a stool, they had two competing ideas—the snack box and a two-step stool design. Eventually the snack box idea won out over the idea for the two-step stool. As the focal group was deciding between the two stool options, they were concerned about how to apply the information from the table with the measurements of the robotics team to their design. The table contained the height and popliteal length for each member of the robotics team. (Popliteal length is the length, when seated, from the underside of the thigh to the bottom of the heel.) The snack box idea won out over the two-step stool even though it did not resolve the issue of how to use the measurement data. Matt challenged the idea of the snack box, saying:

> Before we build the snack box, can we at least figure out what needs we need to engineer for instead of just being, like, oopsie daisy it's a box of snacks! (Transcript March 19, 2018).

Matt wanted to use data to understand the user before the group made the decision to go with the snack box idea ("can we at least figure out what needs we need to engineer for?"). Matt argued in his comment that the group was making rash decisions without any information to justify their choices ("oopsie daisy it's a box of snacks!).

The group never responded to Matt's comment directly. Instead, Rick began building a cardboard prototype, which he completed during the class period, and Emma and David went back to look at the data table. Soon after Rick started working on the prototype, David pointed out the importance of the popliteal length:

> David: Here's another important part... here's what you have to write down, the mean popliteal length for every body is...47.3 centimeters. And the standard deviation is 2. So that's what we're going to work between. 'Cause we were thinking that there would be, you know how there are like two levels [in the two step stool]?
> Emma: Rick, how tall is that [the cardboard prototype]?
> Rick: This is not, to scale. It's scaled down by 50%.
> (Transcript March 19, 2018)

David pointed out the popliteal length as an “important part” and then Emma asked if Rick was considering this measurement in the design. (“Rick, how tall is that?”) Rick did not say that he had (or had not) considered the popliteal length in his design. He just explained the rough dimensions of the prototype (“It’s scaled down by 50%.”) At this point, the group still seemed to be considering the two-step stool idea in addition to the snack box idea because David referred to the two-step stool (“you know how there are two levels”) at the same time that Emma referred to Rick’s prototype of the snack box. A few minutes later, Rick presented his snack box prototype. (See Figure 15.)

Figure 16: Cardboard prototype of snack box

The group was still concerned about the measurement data, even after Rick presented his stool:

> Matt: We can just look and stuff, and just eyeball it.

> Emma: Do you have the length of our legs? So should we measure our butts?
> Rick: Yeah.
> David: But what about all these other... What about the robotics team? We have to go back and do those measurements now?
> Emma: That's gonna be awkward taco.
> (Transcript March 19, 2018)

Matt seemed to have decided that the group should not consider the measurement data at all ("just eyeball it") while Emma wanted to know if the stool should match certain body measurements ("the length of our legs… our butts"). David thought that the hip length (or "butt" length) was important after seeing the prototype but the group did not have that information ("we have to go back and do those measurements"). Emma did not seem to want to gather more measurement data from the robotics team, especially a "butt" length, which was a more awkward part of the body to measure. ("That's gonna be awkward taco.")

In the final minutes of the class, Rick said, "Emma, I think we're good because this box... my popliteal length (*holds box next to leg*) and my butt (*holds box behind him*)" (Transcript, March 19, 2018). Rick used his own body measurement to prove to the group that his design (that he earlier said was scaled down by 50%) seemed to fit the length of his shin and his hips when he held it next to his body. A few seconds later, Emma said "But people are proportioned different than you, Rick. People have wider hips!" which Rick said was a "fair point" (Transcript, March 19, 2018). After this comment, the group's discussion moved onto a different topic rather than discussing the measurement data further. The group seemed to know that the fact that the prototype (scaled down by 50%) generally fit Rick's body measurements was not good enough warrant for their design ("People are proportioned different than you," "fair point") but they also never decided on what measurements to use and how to use them.

When the students presented their initial snack box stool design to the class, they wrote down the average popliteal length on the poster they used for their presentation but the students never wrote or said how they would use the information. The group seemed to think the measurement data was important, but never agreed on how the measurement data should be applied to their initial stool design. During the presentation, the group also said that they had decided the user for the snack box was someone in a waiting area. “We decided that the better use for our project was going to be in a waiting area” (Transcript, March 22, 2018). During this class was the first time the students mentioned using the stool in a waiting area. (In David’s quote above, he talked about using the stool to fix the robot or in the stands.) This gives evidence that the students were still designing the stool for multiple different populations and had not decided on one user.

The texts in the stool design challenge might have been useful for warranting the design of a stool. The data table did not contain the hip measurement and the students did not collect a wide range of interview data, but they still had some information they could have used to warrant their designs. Yet, the students did not use the interview data or the table of measurement data to make design choices—to build evidence that would help them decide on a user and build evidence to help them decide the measurements of their stool. It seemed that the students were aware that their work with the interview notes and data table were related to their task to design a stool. In the 12 days of instruction that proceeded the design challenge, students had learned about different kinds of interviews, but they did not practice interviewing. The students learned how to measure the human body and practiced taking measurements but they did not practice reading or interpreting a data table.

It did not seem that students knew how to apply the data from interviews and the data table to their stool design. For the interview notes, perhaps this occurred because the students that were interviewed had many different ideas of what they wanted and the focal students did not know how to interpret this data to make a design choice. They could have collected and organized a larger amount of data, read over the data to look for patterns, and then decided which design ideas to prioritize based on the evidence from their notes. Instead, they seemed to be unable to draw conclusions from their first few interviews, perhaps seeing inconsistencies in the interview data that made their decisions harder to make.

For the data table, the focal students had some ideas of summary data (the mean, median, mode, and standard deviation) but they did not seem to know what measurements to use and how. For example, if the students had decided to use the standard deviation, how would they have used that measurement to design a stool? Perhaps the standard deviation of the popliteal length could be a measurement the students used to decide the height of the stool but they did not seem to know if that measurement was useful (and if it were useful, how it could be applied). Also, perhaps the students did not collect the data at the best time. A few days into the project, the students remarked that other measurements (hip measurements) would have been useful but they did not seem to want to gather these measurements. If the students had taken measurement data after a few days of working with their prototype, they likely would have asked for hip measurements in addition to popliteal length but they were only given time to collect data once before they had an idea of what their stool would look like.

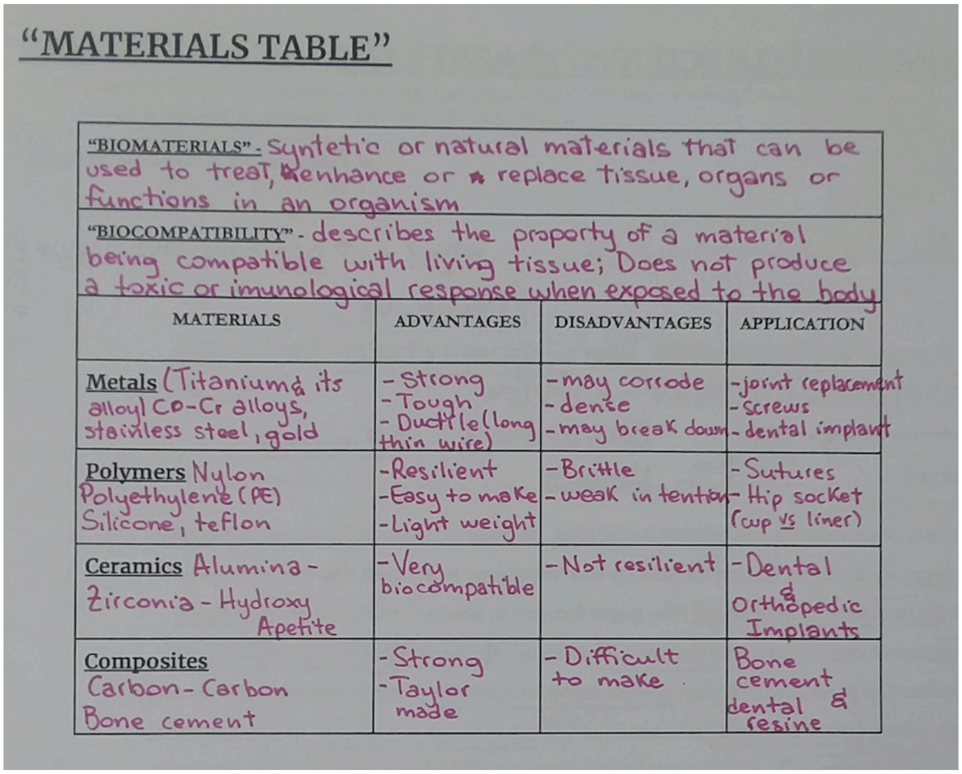
Overall, both the data table and the interview notes were texts that students might have seen in other content areas (though interview notes are less common to other high school subject areas than data tables). However, they did not seem to have the engineering literacy knowledge and skill to use these familiar texts in service of their engineering design projects.

No Text for This: Students Work with a Table and Sketches to Design Hip Implants.

In the high school biomedical engineering course, Ms. Walsh stated that she had difficulty finding texts to use during the design challenge, saying "There's nothing I can use for it. Anything that does exist is too overwhelming and I can't water— I can't give something so overwhelming" (Interview, April 9, 2018). Ms. Walsh had participated in a program at the Hasso Plattner Institute of Design at Stanford University during the summer to design the curriculum for her course. She had searched research databases and the internet. She had visited and interviewed engineering teams in different parts of the country (Interview, May 16, 2018). She eventually decided to use one article abstract and graph (discussed in Chapter 5) and a table with information about biomaterials. Students made sketches and read the biomaterials table to create their hip implant designs.

Ms. Walsh introduced the biomaterials table through a lecture that took approximately 40 minutes of class. She walked through each box of the table in order, giving a definition of "biomaterials" and "biocompatibility," which the students copied into their own table, and then she discussed each category of biomaterials (metals, polymers, ceramics, composites) explaining the advantages, disadvantages, and applications of biomaterials in each category. (See Figure 17.)

Students worked from this table to create their initial hip implant sketches. They sketched four hip implants (cemented, uncemented, hybrid, or reverse hybrid). Each hip implant had four parts (a head, stem, cup, and liner). Each part had to be made of two materials (either a metal, polymer, ceramic, or composite). Students referred to the table to sketch their designs, and they did so with very little communication. On the first day, they spent 20 minutes sketching the cemented and uncemented implants. On the second day, they spent eight minutes sketching the



“MATERIALS TABLE”

“BIOMATERIALS” - Syntetic or natural materials that can be used to treat, enhance or replace tissue, organs or functions in an organism

“BIOCOMPATIBILITY” - describes the property of a material being compatible with living tissue; Does not produce a toxic or imunological response when exposed to the body

MATERIALS	ADVANTAGES	DISADVANTAGES	APPLICATION
Metals (Titanium & its alloy) Co-Cr alloys, stainless steel, gold	- Strong - Tough - Ductile (long thin wire)	- may corrode - dense - may break down	- joint replacement - screws - dental implant
Polymers Nylon Polyethylene (PE) Silicone, teflon	- Resilient - Easy to make - Light weight	- Brittle - weak in tention	- Sutures - Hip socket (cup vs liner)
Ceramics Alumina - Zirconia - Hydroxy Apetite	- Very biocompatible	- Not resilient	- Dental & Orthopedic Implants
Composites Carbon - Carbon Bone cement	- Strong - Taylor made	- Difficult to make	Bone cement & dental resine

Figure 17. Sofia’s biomaterials table

hybrid and reverse hybrid. (The hybrid and reverse hybrid were created from parts of the cemented and uncemented implants so they only had to match the corresponding parts; they did not have to choose new materials for these implants.) Sofia did all of the sketching, although Jenny also contributed ideas. (Ella was absent, and Meg did not speak during the sketching.) Figure 18 is a picture of the sketch for the cemented implant. Sofia started by drawing the implant, then she wrote “cup, liner, head, and f.stem.” Then she wrote the two kinds of biomaterials for each part of the implant. (For example, she wrote “metal” and “polymer” next to the cup.) Finally, Sofia and Jenny went through and chose a material from the table for each category of biomaterial. For example, Sofia wrote “TI” and “Teflon” for the cup (Fieldnotes, April 30, 2018).

The students could memorize the name and properties of each biomaterial, essentially choosing information from the biomaterials table but they were limited to the information in the

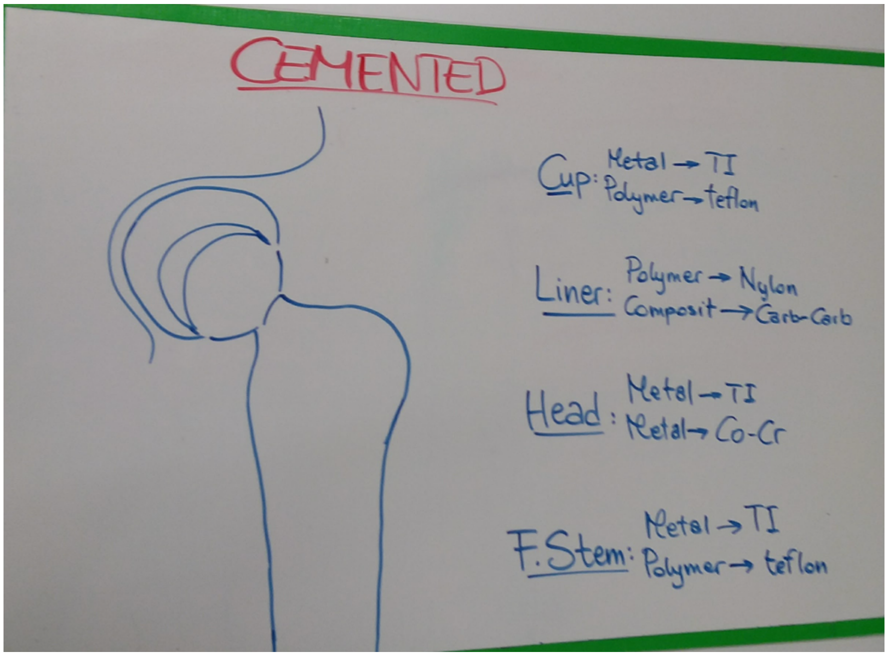


Figure 18. Group sketch of cemented hip implant

table and this material alone was not enough to create a strong warrant for their design. On the day of the final presentations, Meg and Jenny prepared for their presentation by remembering the name and properties of each biomaterial:

> Jenny: Do you know all of these?
>
> Meg: The clay is zirconia. The hot glue is nylon.
>
> Jenny: What is zirconia?
>
> Meg: A ceramic. And then the nylon is a hot glue which is a polymer and the paint is carbon-carbon which is a polymer.
>
> Jenny: The polymer ends with -on, nylon and carbon.
>
> Meg: The smooth foam is titanium and the rough foam is hydroxyapatite and then the liner is nylon which is a.... composite
>
> Jenny: Polymer
>
> Meg: Polymer is the "on" one I know. I'm going to do it again. So the … is zirconia which is a polymer
>
> Jenny: Ceramic
>
> Meg: Clay represents zirconia... ceramic is like you make a pot, that's ceramic. And why are we doing ceramic, cause it's strong and biocompatible. Ugh!
>
> (Transcript, May 16, 2018)

Meg and Jenny looked at each part of their prototype. They named the material in the prototype and the biomaterial it represented (“The clay is zirconia. The hot glue is nylon.”). When they wanted to know what a material was (“What is zirconia?”) they did not have any information beyond “a ceramic.” The students thought of memory tricks to remember the information (“The polymer ends with -on, nylon and carbon,” “Clay represents…ceramic is like you make a pot, that’s ceramic”). They worked through the information several times (“I’m going to do it again.”). They did not seem to enjoy this process, as represented by the “ugh.” (Meg let out her own “ugh” a few minutes later.)

Using the chart and the sketches, Meg could memorize “polymers are nylon, polyethylene, silicone, and Teflon. They are resilient, easy to make, and lightweight but brittle and weak in tension.” This response does not give evidence that Meg could define a polymer or knew why polymers were resilient and easy to make (or why they were brittle or why she had chosen a material that was resilient but also brittle). Meg did warrant her design, but it could have been a stronger warrant if she had known why she had chosen a polymer for the femoral stem or liner of the cemented implant beyond the statement she memorized from the table.

Sofia was able to explain her decisions with a little more detail and with some justification on the day of the final presentation:

> So the cemented [hip implant] is used when the definitions of the bones are not really good, so there's no room for the bone to grow so we need bone cement but the problem with the bone cement is with time, 10-15 years the cements loosens and gets into the body which can be really dangerous. To avoid that we created a bone cement which is sanded (Sofia, Transcript, May 16, 2018).

Sofia added some information from a class lecture on the problems with bone cement (Fieldnotes, April 25, 2018). Her solution to this problem was to use a sanded bone cement in her design. Without any text, how did Sofia get the idea to use a sanded bone cement? It was not information from the table or class lectures. Sofia said that she got this idea from her father, a dentist. “I saw my father and he told me that the sanded, it adhered better to the bone to go into the small pores” (Transcript, May 16, 2018). Sofia had a lot of exposure to scientific text outside of class. Her father sent her medical articles and they discussed these articles together (Interview, May 10, 2018). Sofia was able to piece together information from what she was given in class and what she learned on her own outside of class to justify her design choices.

However, the other students did not have access to this information. During the days of the design challenge, the students did not discuss the information in the table, as it was already organized. This meant that the transcripts from their observations were quite short for a full hour of group work. (Transcripts were, on average, five pages long.) The majority of the transcripts (especially on the first and final day of the design challenge) were instances of students remembering what they had sketched. The students remembered aloud 22 times on the first day of the design challenge and 19 times on the final day. For example:

> Sofia: The head was... what was the polymer? (Transcript, May 1, 2018)
> Jenny: Carbon? Sofia: Yeah, it's carbon to carbon, like two carbons. I don't know. (Transcript, May 2, 2018)
> Ella: The femur head is hot glue and Styrofoam, nope, yeah and then metal and ceramic... clay and smooth Styrofoam. Yep. (Transcript, May 14, 2018)
> Meg: That is what? Sanded, like sand. (Transcript, May 14, 2018)

In these examples, Sofia needed help remembering what polymer composed the head of the cemented implant (“what was the polymer?”). Jenny guessed at what one of the composites was on the hip implant liner (“Carbon… I don’t know”). Jenny knew that this material was “carbon to carbon” but did not exactly know what the material was. Ella needed help matching the materials in the prototype to the biomaterials they represented (“femur head… Styrofoam, nope, yeah”) and Meg pointed at different parts of the prototype asking what they were (“That is what?”). This “remembering” was the most common kind of talk that happened during the group work, and this was only the memorization that happened verbally and was recorded in the transcript. The students also looked back at the table and their sketches to memorize the properties of their designs. The students memorized in different ways. Jenny and Meg talked through the information on the table and in the sketches, quizzing each other. Sofia and Ella created notes where they listed the type of biomaterial, the biomaterial, and the common material used in the prototype. They used this document to reorganize and remember the materials they had used in their design.

The students comprehended the table of biomaterials and used the table as they sketched their hip implant designs. However, because this was the only way the focal students could access the information contained in engineering text, the students' work involved a lot of memorization, remembering the information the teacher had told them. The students memorized their teacher's interpretations, that certain materials were "strong" or "resilient," rather than making meaning of text and drawing their own conclusions about the nature of the biomaterials. This memorization might have taught students something about biomaterials, especially in combination with the prototyping (presented in Chapter 5) where students could learn about how certain biomaterials might look and feel. However, this example also illustrates the limitations of working though a design challenge without accessible texts that students can use for research. For example, if students could have read about what polymers are and how polymers are used in different applications, they could form their own idea about how polymers are resilient and also under what circumstances they are too brittle and do not work well. They could use this information to choose why they decided to use nylon compared to other polymers (and other biomaterials) in a particular aspect of their design instead of choosing the material from a list. This kind of work could support students to build stronger warrants from their design (and also to learn more about polymers). However, without a text the students' learning was limited to what could be conveyed through class lecture and this format did not give students the opportunity to choose what they would like to read or let them read at their own pace. The lectures gave students information they needed to build their prototype but they did not develop the ability to guide their own research and develop independence as they worked with engineering text.

Conclusion: Reading and Writing Across Multiple Texts to Warrant a Design Solution

The purpose of reading across the many texts in each engineering classroom was to warrant the design solution, to gather evidence to argue that the design worked to solve a specific problem for a targeted group of users. In the eighth grade science class, students collaboratively wrote a table with voltage of several batteries and collaboratively interpreted this table in whole-class discussion led by Dr. Meyers. The students read about the metals they had tested from a packet of metal readings excerpted from an industry website. The students had to come to consensus in their small groups to rank the batteries according to how safe they were for human health and the environment. The students wrote their idea for the best battery in a report and got feedback from a partner (and Dr. Meyers) to rewrite their reports. Both the texts and tasks supported students to develop their ideas for which battery was best for a camping flashlight and to warrant their idea with textual evidence.

In the high school engineering design class, students were given the freedom to design their stools for six full class periods after receiving 12 days of instruction. They had data that they could have used to make decisions about who to design for (interview data) and how to create their design (measurement data from robotics team members), but they did not use this data to make decisions. Their data might have been lacking some useful information, such as hip measurement and a larger sample of interview data. Or the activities of the classroom, the six full periods of independent work, might not have given students the guidance they needed to apply what they had previously seen in class in the 12 days of class lectures and activities.

In the high school biomedical engineering class, students sketched their implants using a table of biomaterials with information about metals, polymers, ceramics, and composites. The table gave students information to make decisions about what materials to use in their design. However, the table only provided a limited amount of information so students did not have all the information they needed to make informed design choices and warrant these choices. Instead, they had to rely on the information in the table— that certain materials were “resilient” or “brittle” without understanding how the materials possessed these qualities.

In all three classrooms, the texts and tasks enabled (or did not enable) students to engage in engineering literacy practice— that is, to draw conclusions across texts in ways that an engineer might, to warrant a design solution. In the following chapter, I will discuss the findings in Chapters 4, 5, and 6 to examine the qualities of texts and tasks across the three classrooms and draw implications for research, policy, and practice aimed at supporting students to engage in engineering literacy practice inside of an engineering design challenge.

Chapter 7 Discussion and Implications

In this chapter, I discuss the findings and draw implications for future research, policy and practice. First, I will present a short overview of the findings to illustrate the nature of opportunities that students had to engage in literacy inside of engineering design challenges. Then I will focus on two major themes in the findings. First, I will discuss the nature of tasks across the three classrooms, focusing on the role that reading and writing could play to support students to engage in engineering inquiry. Second, I will discuss the nature of texts that support engagement in engineering literacy (and engineering practices). I will conclude the chapter by drawing implications from the discussions of tasks and texts for researchers, practitioners, and policy makers.

Overview: Reading and Writing Opportunities Across the Three Classes

The findings presented in Chapters 4, 5, and 6 show that students made many attempts to engage in engineering literacy (to realize a solution, delimit a problem, or warrant a design) but students were not always able to follow through with these attempts to read and write in ways that affected their design solution. For example, some of the focal students building a solar car in the eighth grade class attempted to read and write to realize a solution as they built a solar car from a diagram but by the time they were able to build their first car the design challenge was almost over, and they did not have time to optimize their solar car solution. The focal students in the high school engineering design class attempted to read and write to delimit a problem by collecting and analyzing interview data, but they did not draw conclusions from the data to apply to their stool design. The students in the high school biomedical engineering class attempted to warrant their designs with evidence from a table of biomaterial properties but their warrants were limited to information they had memorized from the table so they struggled to create their own explanations for their design choices. In some of these cases, such as the example of the interview data from the high school engineering classroom, students did not seem to be aware of how the reading and writing could help them solve engineering problems. Students did not seem to be aware that the interview data could help them make design choices. In other cases, for example when the eighth grade students built solar cars from a diagram, prior experience seemed to play a role. Students encountering new engineering text for the first time lacked the literacy knowledge and skill (and perhaps also knowledge of the materials and general experience with building) to work with engineering text. In other cases, like in cases such as the example of warranting a hip implant design in the high school biomedical engineering course, the teacher was not able to find appropriate texts for students to use, and this lack of text limited students' attempts to warrant their design. The findings suggest that students needed: (1) awareness of how reading and writing could be used to solve engineering problems, and (2) the literacy knowledge and skill to create and interpret engineering text, and (3) access to accessible text with useful information.

Furthermore, in some instances of literacy engagement, students appeared to have successful reading and writing opportunities yet these opportunities were not connected to the work of designing an engineering solution. In the eighth grade classroom when students read the article about the Battery Act, the high school engineering course when students worked with the data table of body measurements, and the high school biomedical engineering course when students read the article abstract about titanium implants, students were not frustrated with reading and writing, and they did not give up on their attempts to read and write. Students read and wrote with comprehension and fluency. They appeared to have success in their work with text yet, although they likely learned some facts related to the topic of the design challenge, the students did not draw conclusions from text that influenced their design solutions. The purpose of the reading and writing seemed to be for students to accumulate general knowledge related to an engineering topic while the purpose of the design challenge was for students to design an engineering solution. Although students looked like they were designing a solution when they read and wrote, students did not use text to inform their design solution.

Research argues that professional engineers read and write to sustain many aspects of their work—to manage projects and collaborate with peers (Pogner, 2003; Tenopir & King, 2004; Windsor, 1989), to innovate and solve engineering problems (Giroux & Moje, 2017; Suchman, 2011), and to communicate about their work with the outside world (Brown, 1993; Selzer, 1983; Tenopir & King, 2004). This research argues that reading and writing are tools that support professional engineers to engage in their work. The research shows that engineers have literacy knowledge and the literacy skills to read and write to communicate and solve problems around a variety of engineering text. The research also suggests that engineers are not engaging in reading and writing solely for the purpose of improving their general knowledge, but that they engage in reading and writing for an immediate purpose in their daily work.

So what might have caused this disconnect between reading and writing and the work of the design challenge, especially in classrooms led by experienced teachers? Both Ms. Walsh and Dr. Meyers were seasoned educators who were well-regarded by their students. Dr. Meyers had a PhD in science education and 18 years of teaching experience in middle and high school. Ms. Walsh had a master's in science education and seven years of teaching experience. The students in each focal group all completed design projects in Ms. Walsh and Dr. Meyers classrooms, and they all reported that they enjoyed their engineering class. Yet even in these classrooms led by experienced teachers, students initiated reading and writing but could not follow through in ways that might have helped them create a design solution; they engaged in reading and writing disconnected from the process of designing a solution.

Two discussions are worth having in light of this "disconnect." First, it is important to discuss the tasks of the design challenge and what literacy teaching and learning add to the teaching and learning of engineering design. Second, if literacy teaching and learning enhance engagement in engineering design, it is worth discussing the nature of texts that support engagement in engineering literacy. In what follows, I will discuss these two aspects (the tasks and texts) of youth engineering literacy engagement.

Reading and Writing are Tools for Engaging with Engineering Practices

It is not enough to say that engineers read and write in their work and therefore young people should also read and write (or even that engineers read and write therefore young people should learn how to read and write in the same ways to prepare for college and career). The "engineers do it so children have to do it" argument might give researchers and practitioners the wrong idea about why (and how) to engage students in literacy learning in engineering design challenges. Instead, a better argument is that reading and writing are tools for engaging in inquiry, and (in addition to increasing engineering knowledge) students can read and write to understand, engage in, and even critique, the ways that disciplines produce knowledge. As Moje (2007:8) argued "some of the power of knowledge comes from being an active part of its production rather than from merely possessing it." Engineering literacy engagement supports students to sustain (and experience) inquiry in engineering and includes the literacy knowledge and skills to frame problems, work with data, consult and produce multiple types of text, analyze and synthesize findings, and evaluate and communicate claims (Moje, 2015). Therefore, it is worth considering how an opportunity to engage students in reading and writing to delimit a problem, realize a solution, and warrant a design could be an opportunity to develop knowledge of (and experience with) the inquiry practices (or knowledge-generating practices) of engineering.

One example to read and write to realize (and warrant) a solution from the high school engineering design course was the opportunity that the four focal students had to document how their cardboard timer worked. The students wrote down three time trials and the students made verbal observations of their timer, but they did not write the vast majority of these observations on paper. This might have been an opportunity for students to understand what engineering data looks like and how to record, organize, analyze, and interpret data—to realize the solution. This data also could have been evidence to warrant their timer design.

The students completed the design challenge. They created a cardboard timer that made a bell go off after 20 seconds. I do not want to say that the students did not learn something about engineering inquiry as they designed their timer. They likely did. Instead, I argue that reading and writing (as tools) could have afforded students three ways to problem-solve and understand their timer in greater depth: through reflection, information-sharing, and evidence-gathering.

First, reading and writing would enable different forms of *reflection* and lead to deeper understanding of a design solution. As students recorded the time and recorded some notes on each time trial they would create two different ways to think about their timer. They would be able to see aspects of their timer's function represented in numeric form and through written notes. Each of these notations would have characterized the function of the timer differently than a visual observation and students could reflect on their timer's performance by reflecting across these three sources of data (memory/observation, numerical data, and written notes), adding depth and nuance to their understanding of their design solution.

Second, through reading and writing students could have opportunities to *share information* and communicate multiple perspectives on the data. Through small group discussion, students could see what their peers noticed in the data and how their classmates' viewpoints differed from their own. Students could start to see patterns in the data in small groups or with the guidance of their teacher and could draw interpretations of the data based on these patterns. Students could hear their teacher's more experienced interpretation of the data, which could help students to form their own understanding of how to read and interpret data as an engineer would. Students could share their interpretations in groups or with the full class to learn how to evaluate their interpretations and the interpretations of others. Students could not share their work with others if the only data they had were their own memories of the timer.

Third, through reading and writing students could engage in textual *evidence-gathering* to inform their design choices. After weighing the evidence, students could make a decision about an aspect of their design and record evidence from their documentation to explain each design choice. At the end of the design challenge, students could have used textual evidence to argue that their design was efficient. Without documentation, students would not have any textual evidence to "back up" the choices they made or the design they created. The focal students' individual memories of how their timer worked did not agree and, even if they had, memories change (or fade) over time in a way that text does not. Textual evidence is stronger evidence than an individual memory.

In short, reading and writing enables students to understand a phenomenon in multiple ways. Reading and writing allow for reflection and for the sharing and evaluation of knowledge.

This is an example of how language is a “tool of thought” (Vygotsky, 1978, p. 176) and writing is a tool that “brings awareness to speech” (Vygotsky, 1986, p. 183). Through writing, an individual can encode and reflect on his or her memories, allowing for greater awareness. Language and literacy are tools for understanding and problem-solving; they are “a means by which human external activity is aimed at mastering, and triumphing over, nature” (Vygotsky, 1978, p. 57). Although the concept of “mastering nature” seems a bit ambitious for a high school engineering design challenge, Vygotsky talks about mastering nature in the context of child development, noting the ways that young children explore the world around them through relationships mediated by language. In the high school engineering design classroom, students could have used literacy tools in the same way— to understand more about the world around them. The students could read and write to understand how a man-made piece of technology (their timer) functioned under real-world conditions.

Yet, this is only one reading and writing opportunity that could have supported students to produce knowledge using the same literacy and language tools that engineers use to engage in inquiry. The point of this example is that any implications drawn from this dissertation study should consider the ways that opportunities for students to read and write (to delimit, realize, or warrant) could be opportunities to engage students in engineering inquiry in ways that, over time, help students to understand how engineers produce knowledge—how engineers create multiple textual representations to understand how a piece of technology functions and the many other ways that reading and writing support engineers to engage in their work.

Discussion of Text, Reader, and Context: The Interaction that Supports Interpretation

In Chapters 4 though 6, I presented several examples of texts that the focal students could comprehend but did not use in ways that supported their design work. The hip implant article abstract, the “Battery Act” article, and the data table of robotics team body measurements are examples of some of these texts that students could comprehend but observational and interview data showed that students did not use these documents to help them design a hip implant, a battery, or a stool. In this section I will focus on the interpretation of text—how it occurs in the interaction between reader, text, and context, and what elements of this interaction might have affected the processes of interpretation in the three classrooms of this study.

Reading research argues that a reader draws an interpretation from a text as a result of the interaction between the reader, text, and context (Kintsch, 1998; Moje, Dillon, & O’Brien, 2000; Rosenblatt, 1994; Snow & Sweet, 2002). A reader builds the “textbase” through decoding and word-recognition processes and by building coherence as he or she moves from words to sentences to paragraphs over the course of a text. An interpretation occurs in this interaction between reader, text, and context as the reader builds a “situation model.” A reader applies their background knowledge and experience as well as knowledge of the social context (the “situation model”) to the explicit information from the textbase to create an interpretation of a particular text (Kintsh, 1998). To explain why the focal students might not always have interpreted classroom texts in ways that could help them with their engineering work, I will discuss two elements of this interaction: the text and the context.

The Text. For a text to support interpretation, the text should align with a reader’s prior knowledge. A text with a high density of new words, for example, can affect a reader’s ability to construct meaning of the text and interpret the text in a particular context (Snow & Sweet, 2002). This might account for the struggle that the focal students in the biomedical engineering class experienced while trying to comprehend the article abstract about titanium implants. Despite Ms. Walsh’s best efforts, the students found the text challenging after multiple readings. However, the findings presented more examples of texts that students could comprehend but did not interpret in ways that supported their work. Both Dr. Meyers and Ms. Walsh chose primary source documents (such as the abstract from the article about titanium implants or the “Battery Act” article) to include in the design challenge, which suggests that the teachers sought to provide students with the experience of reading the same documents as an engineer would. (Dr. Meyers discussed his choice to have students work with “primary source” texts, or the texts “that you would see if you had a job,” in an interview on December 18, 2018.) The students had documents that engineers would read and had students read these texts in the context of building a prototype and working with an engineering design challenge, but my findings show that the activity and the primary source text alone were not always enough to support students to think and use texts as engineers would.

The “Battery Act” article is one example of a text that might not have contained information that students needed to design their batteries. During the battery design challenge, students had to choose a battery that produced voltage (0.5 volts) and was generally safe for humans and the environment. Knowing, for example, that there was a law that governs battery disposal might have been tangential information that students did not need to complete the battery design challenge.

This is not to say that all the documents were not useful for the students. The packet of metal readings from the middle school battery design challenge was an example of an authentic engineering text that students were able to comprehend, interpret, and apply to the design of a battery. The packet consisted of excerpts taken from the Lenntech company website (a company specializing in water treatment solutions). Students discussed the text in small groups to decide what metals were safest to include in their battery. They also used information from the metal readings in their reports to argue that their battery was composed of metals that were safe for humans and the environment. Based on observations of the group discussion and from the students' final reports, the packet of metal readings seemed to deepen students' knowledge of the data table that contained the voltage of each metal. The students understood they were choosing among these metals to design the "best" battery for campers. Having this information about qualities of the metals— beyond just their voltage— helped them make decisions about which metals were best.

In the biomedical engineering design class, students read the article abstract and graph from an article about titanium hip implants. The students did not apply information from this article to their design of a hip implant. This might have occurred because the abstract did not have information that they could have used to make decisions about the design of the implant beyond the main idea that titanium was biocompatible. It is possible that this primary source did not contain useful information. However, Ms. Walsh also reported her frustration that she could not find any texts that were useful for designing a hip implant that also aligned with students' prior knowledge and experience. It is possible that Ms. Walsh knew the article abstract was not very useful, but she used it because it was the only article she could find.

The Context. Particularly in the high school engineering design course, all four focal students were what would be considered college-ready by most common metrics, such as grades and test scores. They could comprehend a variety of subject-area texts well enough to pass college entrance requirements and examinations. However, the students did not appear to understand how to read (and also write) certain engineering texts such as interview data, data tables, sketches, and documentation. The focal students in the engineering design class were successful communicators, readers, and writers in other school subjects but sometimes struggled in their first experiences reading, writing, communicating, and thinking as engineers. For example, they struggled to understand how to use interview data and a data table as an engineer would. They comprehended the information but did not know how to use it to create an engineering design solution. They had likely seen many data tables before, but they struggled to understand how to use the information in the data table of robotics team measurements in their prototype. Similarly, the students had likely interviewed people before, but they did not seem to know how to gather and analyze data to solve an engineering problem.

Literacy research argues that students are cultural navigators who employ different ways of thinking, doing, communicating, and being in the different cultures of home, school, and community life (Alvermann, 2002; Alvermann & Moje, 2003; Moje, 2015; Moje, 2008). To build a warrant for the design of a stool, they would have to understand what "counts" as evidence in engineering and how engineers read to build evidence for design choices. Instead it seemed that students went through the motions of conducting interviews, understood what respondents said, and could even draw patterns in what respondents said. They later went with the idea of a snack box because they liked the idea. In other words, they did the work to collect data about a user population but later ignored the user in their design. If students had understood about how an engineer might work with a data table to design a solution, they might have behaved differently. The students might have read to notice patterns in the data and drawn an interpretation about what their user wanted that would have helped them design a stool.

This example shows that students might have understood some aspects of the design challenge as a building activity or a creative endeavor similar to an art project. Yet, engagement with engineering inquiry does not only mean building and engineers cannot build only what they like to build. If we are to teach students to engage in engineering inquiry then we must begin with an understanding of the field of engineering as a culture with norms and values that shape inquiry practices (Moje, 2015) and “ways with words” (Heath, 1983) that mediate engagement with these practices. Engagement in inquiry practice means asking and pursuing questions about the world in a way an engineer would (not like an artist, technician, builder, crafter, or member of any other related field). It requires students to take up the language tools that would support them to ask and pursue such questions. Just because a student builds a prototype or writes about an engineering problem (or completes any other kind of engineering activity) does not mean that the student has participated in engineering inquiry. To participate in inquiry through prototyping (for example), a student would have to build a prototype following the same cultural norms as an engineer and use the same language and literacy tools as an engineer. If the student follows different norms, for example taking a creative license to represent the size, shape, and color of the prototype as an artist might, they are not prototyping as an engineer would. Instead, an engineer might use measurement tools or software to create an accurate scaled model using prototyping materials and this would require literacy knowledge and skill to sketch or use CAD software. Therefore, it is important to conceive of engineering teaching as apprenticing young people into the human, social practices of the discipline and to create engineering design challenges that provide opportunities for students to experience engineering norms and engage in the reading and writing of engineers.

Implications for Researchers

This study documented three literacy practices at work among focal students in three classrooms (the literacy practices of delimiting, realizing, and warranting) but this was only one small step in uncovering the ways that students can learn to read and write to participate in engineering inquiry. Specifically, it is worth investigating how engineers interpret different types of texts in their work. While other disciplines have research that sheds light on the interpretive processes of disciplinary professionals (Rainey, 2017; Shanahan & Shanahan, 2008; Wineburg, 1998) very few studies of professional engineers focus on processes of interpretation. This research would be useful to education researchers by explaining how to best engage students in reading and writing in a way that supports engagement in the engineering design process. For example Chapter 4 showed that the focal students in the engineering design class seemed to struggle to interpret interview data and suggested that a solution would have been for them to look over the data for patterns that could have influenced their design choices. If there was research that discussed how engineers collected, organized, interpreted and applied interview data, it might show that engineers do more than look for general patterns and then directly make design choices. Research could illuminate this aspect of engineer reading so that it could then be taught to students to support their engagement in the engineering design process.

In addition to research in the reading and writing of professional engineers, student engagement with engineering literacies in K-12 classrooms is also worth further study. Future research could examine how students engage in engineering literacy in different contexts, with different kinds of engineering design challenges, and with varied text types that were not part of this investigation. Design-based research that seeks to engage students in the literacies of professional engineers in age and grade-appropriate ways could begin to map elements of a reading and writing trajectory from kindergarten through twelfth grade. Finally, data from interviews with Ms. Walsh suggests that engineering teachers may not have text that is appropriate or useful for teaching and sustaining reading and writing in engineering classrooms. Future research in collaboration with engineering teachers could develop texts that would be useful for K-12 engineering teachers and students.

Finally, in preparing the literature review of this study, I found that it was very rare to see partnerships between engineering departments and education (or literacy) departments. Furthermore, the vast majority of articles in *Engineering Education* and curricula surveyed by the Academy of Engineering (Katehi, Pearson, & Feder 2009) do not attend specifically to literacy teaching and learning. My study has shown how reading and writing supported students in three classrooms to engage in the engineering design process— that students engaged in this process through reading and writing (or felt frustrated when they did not know how to read and write to engage in the design process). In this way, the dissertation study is an argument for engineering education research, curriculum, and initiatives that include attention to literacy teaching and learning, ideally through partnerships between engineering education researchers and literacy researchers.

Implications for Practitioners

The NGSS argue for engineering teaching and learning that engages students in the practices of engineering (in age and grade appropriate ways), and the findings from these three classrooms show some of the complexity in engaging young people in social practice. It might be easy to distill the NGSS practices into a list of isolated skills or activities that students complete within a lesson. To make an example using a common text across the three classrooms, in a classroom activity, students might read a data table with the instructions that they use the data to help them design a solution. Students might make comments about this data table in their group or answer comprehension questions about the data. However, having completed this exercise, have the students really worked with the data as an engineer would? Or have they decoded the words and numbers on a page and made some comments about that information that will not help them to create a design solution? In one context, reading and writing could be tools of engineering inquiry; in another context they could be an exercise that is disconnected from engagement in the engineering design cycle.) Teachers working in engineering classrooms may not yet have the research that can inform their practice in ways that shed light on how engineers engage with certain types of text. If they had this knowledge, teachers also may not have the resources (such as classroom texts) that will sustain this work. However, implications drawn from this work, while not generalizable to a population beyond the three classrooms, can provide guidance for teachers who want to design engineering design challenges that engage students in using reading and writing as tools that support engineering inquiry.

The product of the engineering design cycle is a prototype (or actual) design solution. In the design challenges that I observed in this study, students began to put forth designs from the first minutes of the challenge, designs that evolved through optimization over the course of the design challenge. In addition to this physical product, students also produced an intellectual product, a warrant for their design, that was the result of reading and writing across multiple text types throughout the design challenge. Students began warranting from the time they shared their first design ideas, and their warrants improved over the course of the design challenge as students developed textual evidence to warrant the physical aspects of their designs. Optimization of the design was a process of gathering and interpreting textual evidence, and while students also gathered and interpreted other kinds of evidence (such as evidence from a single observation of a prototype) the textual evidence (such as documentation of how the prototype worked at different times and in different conditions) built a stronger warrant for the design. One way to engage students in reading and writing as engineers is to provide instructional support for students to read and write to warrant their ideas throughout the design challenge. This would mean attention to the text, to choose texts that contain information useful for warranting a certain design solution, as well as texts that aligned with a reader's prior knowledge and were not at a "frustration level" for students. Teachers can also attend to the larger social context of engineer reading and writing, to teach why and how engineers read to warrant a design. Teachers can model reading and writing to warrant a design and have students share their processes of warranting their designs.

Evidence from the initial stool presentations in the high school engineering design class showed that students included evidence from text in their presentation. They listed data on their posters and, in their verbal presentations said how they had used that data in their design. Yet observational and interview data before this presentation showed that students were confused about how to interpret and apply the data to their stool design. I bring up this example as evidence that asking students to warrant their designs with data may not be enough to support students to engage in this literacy practice as engineers would. Students may follow the teachers' directions, piece together a presentation that looks like they have used data, and never reveal their confusion and frustration. One reason for these students' confusion may have been their lack of experience with engineering reading and writing, which means that teachers should investigate their students' experience with certain texts and provide extra support for students who are working with engineering text (or familiar text in an engineering context) for the first time. Also, teaching and modeling the practice of warranting means teaching reading and writing of each classroom text as well as across text. Students will need to understand the social context, purposes, and practices of working with each individual text as well as the process of working across text.

Implications for Policy

The NGSS do not include standards for reading and writing in science or engineering, which makes it difficult for teachers who understand the importance of literacy teaching and learning to understand how reading and writing can support engagement in the engineering practices. For example, a ninth grade engineering teacher that wanted to support their students to collect, analyze, and apply documentation of a design solution could read in the NGSS that “A solution needs to be tested, and then modified on the basis of the test results, in order to improve it,” and “models of all kinds are important for testing solutions, and computers are a valuable tool for simulating systems” (National Research Council, 2012, p.208). This one example shows how the NGSS mention text (e.g., test results, digital text such as CAD drawings) but do not specify goals for reading and writing. However, the findings of this study showed that simply including text in engineering design challenges did not always support the focal students to engage in reading and writing as engineers. If reading and writing are tools that support students to engage in the practices of engineers (as this study argues), how are reform leaders and practitioners— those tasked with implementation of the NGSS— supposed to bring quality engineering education to students across the country without attention to literacy teaching and learning across the grade span? The NGSS is an ongoing initiative, and—especially at this time when implementation is a focus— it is important for leaders and policy makers to also advocate for the reading and writing that supports students to engage in engineering practice. This advocacy could include funding for research in engineering literacy, the commissioning of reports (similar to engineering education reports by the National Academy of Engineering) that examine the role of literacy in engineering (and in the engineering classroom), and an effort to include information about literacy teaching and learning in ongoing discussions of NGSS implementation.

APPENDICES

Appendix A: Think-aloud Protocol for Reading and Writing

This protocol is to be used for two purposes:
1) in the reading of two different engineering texts before and after a unit of study. In this case, I will use the general prompts (when appropriate) as all 4 sections of the think-aloud protocol in order.
2) when inquiring about student reading and writing during focal observations. In this case, inquiries will depend on the lesson format and the individual needs of each focal student. When a focal student has the time to answer questions, I will choose questions from the list of prompts. If I talk to a student after a period of silent reading, I may choose questions from Section 4 as well.

General prompts:

What are you thinking about?
Tell me more about that.
You said... Could you tell me a little more about that?
You say that because...
What else do you know about this?
Why were you thinking about that?
What were you thinking about when you read...
What does that mean to you?

Text-Specific prompts:

Section 1: Preview Questions

Use these specific questions for each text. (I plan to have one engineering article and one data table. These texts may change depending on the unit of instruction that I observe.)

Engineering Article	**Data Table / "Raw" Machine Output**
Title of article Author What do you think this article will be about? What makes you think that? Have you read this before? (When? What do you know about it?) What do you think about this text? What are you thinking about?	Where does this data come from? What day was it taken? What machine created this data? Do you know how this data was collected? If no, do you have an idea? If no, can you guess? What kind of data does it show? (i.e. if it says 1.5 what is the unit of measurement? 1.5 what?)

Do you think this will be a useful text to read? Why or why not?	Do you know what this data represents? What are these measurements? What do you think about this text? What are you thinking about? Do you think this will be a useful text to read? Why or why not?

Section 2: First section of oral reading (both texts)

Instructions: Have the student read the first two or three sentences of the article and the first two or three lines of the data table.

Script: *I'm going to have you read the first two sentence/lines aloud (from here to here).*

Questions:

1. What are you thinking about now?
2. Can you add to your earlier prediction of what this text is about? OR Can you add to your earlier prediction of what this data is/what it represents?

Section 3: Oral reading

Instructions: Have the student read a section of each passage. (The section has been marked on the text.)

Script: *Here I want you to read aloud from here (point) to here (point). At the end, I'm going to ask you about what you were thinking as you read but if you have an idea as you are reading, you should stop reading and tell me what you are thinking.*

Questions:

1. Can you tell me what this part was about?
2. Did you read anything important or interesting to you?
3. Are there any parts you don't understand?
    - What kind of things do/did you do to understand better?
4. Were there any words you didn't understand? If yes, which ones?
    - What did you do to figure them out?
    - What do you do when you come to a word you don't know?
5. What do you think ____ means?

Section 4: Silent reading

Instructions: The student reads silently to a marked point in the text.

Script: *Here I want you to read silently from here (point) to here (point). Just like we did last time, I'm going to ask you about what you were thinking as you read but if you have an idea as you are reading, you can stop reading and tell me what you are thinking.*

Questions:

1. Can you tell me what this part was about?
2. Can you summarize the whole passage?
3. Did you read anything important or interesting to you?
4. Are there any parts you don’t understand?
    - What kind of things do/did you do to understand better?
5. Were there any words you didn’t understand? If yes, which ones?
    - What did you do to figure them out?
    - What do you do when you come to a word you don’t know?
6. What do you think ____ means?
7. Do you learn something about this already in class?
8. Have you ever read anything similar?
    - Does this text remind you of anything?
9. Why would an engineer read this?
    - What would an engineer do with this information?

Appendix B: Semi-Structured Student Interview

This interview should be given to each focal student towards the beginning of observations to collect general information about the student's background and experience related to engineering and engineering literacy.

Introduction (Read Aloud)

Thank you for allowing me to interview you today. In this interview I want to learn more about you, your interests, and your experiences in school.. I know I've said this to the full class but I'd like to remind you again that you don't have to answer any questions that you don't want to answer, and you can stop the interview at any time. I'm going to use this information to show how your interests and experiences influence your work in class. Although your name will not be on any of my documents, the information you give me will help me to show other teachers and researchers how students learn when they complete engineering design projects. I'm thankful that you are willing to participate! The interview should take 15-20 minutes.

Do I have your permission to record?

Grand-tour questions

1. What do you like best about school?
    - What about school would you change?

2. Do you like engineering?
    If yes, how do you think you came to like the subject?
    If no, what about the subject do you dislike?

3. Do you think engineering is important?

4. Do you think engineering is a career you would consider in your future? If yes, why? If no, why not?

Mini-tour questions

Part 1: Engineering

1. If you had to explain what engineering was to friend, what would you say engineering is?

2. Outside of this class, have you ever done any engineering design work?
    - Follow up prompts: joined any specific clubs i.e. robotics? joined in any engineering activities at after-school programs or at summer camp? played any games that require design or coding? Observed any engineers at work?

2. What do you like so far about the engineering projects? (Prompt with names of specific projects i.e. "The rubber band shooter design project")
    - What do you think is challenging about the projects?

3. Do you like the reading that you have done so far in this class? Why or why not?
    - What about the reading and writing is difficult?

4. Questions with scale.
Show the scale to students on a half-sheet of paper and write down their answers.
For this part, think of the specific engineering design projects you have completed (list specific names, show documents from that project if available).
1. Pose question a-d
2. Inquire for each rating, immediately after the participant says their answer: Why did you choose that rating?

Strongly agree	Somewhat agree	Neither agree or disagree	Somewhat disagree	Strongly disagree

a) I'm good at engineering design.

b) I enjoy engineering design.

c) I feel confident and comfortable reading the texts involved in engineering design projects.
(Prompt with specific texts used in class to remind students what is meant by reading)

d) I feel confident and comfortable writing during engineering design projects.
(Prompt with specific texts used in class to remind students what is meant by reading)

Part 2: Reading and Writing

6. Do you like to read for pleasure?
    - Follow up prompts (about specific texts): novels, non-fiction books, comic books, websites, blogs, newspapers, magazines
    - Follow up: Which (specific texts) do you like to read? (Ask for names, i.e. "facebook" in place of "websites" if not said already)

7. Do you like to write for pleasure?
    - Follow up prompts (about specific texts): stories, notes to friends, letters, comments on the internet, webpages, blogs, video blogs
    - Follow up: Which (specific texts) do you like to read? (Ask for names, i.e. "facebook comments" in place of "comments on the internet" if not said already)

8. In one week, how many hours do you estimate that you spend:
a) reading for pleasure
b) writing for pleasure

c) reading and writing for school

Part 3: Anything Else?

9. Is there anything you would like me to know about you?

10. Is there anything you would like me to know about your work with engineering design projects?

Part 4: Demographic Information

Prompt: *Could you please fill out this information card so I can correctly represent your age, gender identity, language background and ethnic background?*

Question	**Answer**
1. What is your birth year?	
2. Which of the following choices describe your race? You may check all that apply.	☐ White ☐ Black and/or African American ☐ Asian ☐ Native Hawaiian or other Pacific Islander ☐ Hispanic/Latino ☐ American Indian or Alaska Native ☐ Other (please specify:___)
3. What is your gender identity?	☐ Female ☐ Male ☐ Transgender FTM (female-to-male) ☐ Transgender MTF (male-to-female) ☐ Non-binary/gender fluid/genderqueer ☐ Not sure ☐ Prefer to self-describe (please specify:__________) ☐ Prefer not to say
4. Is English your native language?	☐ Yes ☐ No (Specify native language: ___________) ☐ English and another language are my native languages. (Specify other language(s): ______________)
5a Do you read or write in other languages when you do your schoolwork (for example, reading articles or taking notes)?	☐ Yes ☐ No

5b. IF YES, how often do you read and write in this language at school?	☐ very often ☐ fairly often ☐ sometimes ☐ almost never
6a Do you read or write in other languages at home?	☐ Yes ☐ No
6b. IF YES, how often do you read and write in this language at home?	☐ very often ☐ fairly often ☐ sometimes ☐ almost never

References

Alvermann, D. E., & Moje E. B. (2013). Adolescent literacy instruction and the discourse of "Every teacher is a teacher of reading." In D. Alverman, N. Unrau, & R. Ruddell (Eds.), *Theoretical models and processes of reading, 6th edition*. Newark, NJ: International Reading Association.

Au, K. H. (1980). Participation structures in a reading lesson with Hawaiian children: Analysis of a culturally appropriate instructional event. *Anthropology & Education Quarterly*, *11*(2), 91–115.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369–387.

Brown, V. J. (1994). Facing multiple audiences in engineering and R&D writing: The social contexts of a technical report. *Journal of Technical Writing and Communication*, *24*(1), 67-75.

Cejka, E., Rogers, C., & Portsmore, M. (2006). Kindergarten robotics: Using robotics to motivate math, science, and engineering literacy in elementary school. *International Journal of Engineering Education*, *22*(4), 711-722.

Chandler, J., Fontenot, A. D., & Tate, D. (2011). Problems associated with a lack of cohesive policy in K-12 pre-college engineering. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(1), 40–48.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis.* Thousand Oaks, CA: Sage Publications.

Chumbley, L. S., Hargrave, C. P., Constant, K., Hand, B., Andre, T., & Thompson, E. A. (2002). Project ExCEL: Web-based scanning electron microscopy for K-12 education. *Journal of Engineering Education*, *91*(2), 203-210.

Cunningham, C. M. (2009). Engineering is elementary. *The Bridge*, *39*(3), 11-17.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

Emerson, R., Fretz, R., & Shaw, L. (2011). *Writing ethnographic fieldnotes.* Chicago: University of Chicago Press.

Gee, J. (2015). *Social linguistics and literacies: Ideology in discourses*. London: Routledge.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New York: Aldine.

Giroux, C. S. (in preparation) Engineer literacies: What, why, and how engineers read and write.

Giroux, C. S., & Moje, E. B. (2017). Learning from the professions: Examining how, why, and when engineers read and write. *Theory Into Practice*, *56*(4), 300-307.

Gutiérrez, K. D. (2008). Developing a sociocritical literacy in the third space. *Reading Research Quarterly*, *43*(2), 148–164.

Heath, S. B. (1983). *Ways with words: Language, life, and work in communities and classrooms.* New York, NY: Cambridge University Press.

Heller, R., & Greenleaf, C. L. (2007). *Literacy instruction in the content areas: Getting to the core of middle and high school improvement.* Washington, DC: Alliance for Excellent Education.

Jenkins, S., Jordan, M. K., & Weiland, P. O. (1993). The role of writing in graduate engineering education: A survey of faculty beliefs and practices. *English for Specific Purposes*, *12*(1), 51-67.

Katehi, L., Pearson, G., & Feder, M. (2009). The status and nature of K-12 engineering education in the United States. *The Bridge*, *39*(3), 5-10.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*(2), 163-182.

Klein, S. S., & Sherwood, R. D. (2005). Biomedical engineering and cognitive science as the basis for secondary science curriculum development: A three-year study. *School Science and Mathematics*, *105*(8), 384-401.

Knor-Cetina, K. (2009). *Epistemic cultures: How the sciences make knowledge*. Boston: Harvard University Press.

Koutsantoni, D. (2006). Rhetorical strategies in engineering research articles and research theses: Advanced academic literacy and relations of power. *Journal of English for Academic Purposes*, *5*(1), 19-36.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts.* London: Sage Publications.

Lee, C. D. (1995). A culturally based cognitive apprenticeship: Teaching African American high school students skills in literary interpretation. *Reading Research Quarterly*, *30*(4), 608–630.

Lee, C.D., Spratley, A. (2010). *Reading in the disciplines: The challenges of adolescent literacy.* New York, NY: Carnegie Corporation of New York.

Lynch, M. (1985). *Art and artifact in laboratory science. A study of shop work and shop talk in a research laboratory*. London: Routledge & Kegan Paul.

Maxwell, J. A. (2013). *Qualitative research design: An interactive approach (3rd ed.).* Washington DC: Sage Publications.

McKenna, B. (1887). How engineers write: An empirical study of engineering report writing. *Applied Linguistics, 18*(2). 198-211.

McVee, M., Silvestri, K., Shanahan, L., & English, K. (2017). Productive Communication in an Afterschool Engineering Club with Girls Who are English Language Learners. *Theory Into Practice*, *56*(4), 246–254.

Moje, E. B., Dillon, D. R., & O'Brien, D. (2000). Reexamining roles of learner, text, and context in secondary literacy. *The Journal of Educational Research*, *93*(3), 165–180.

Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education*, *31*(1), 1-44.

Moje, E. B. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy*, *52*(2), 96-107.

Moje, E. B. (2015). Doing and teaching disciplinary literacy with adolescent learners. *Harvard Educational Review*, *85*(2), 254-278.

Moye, J. J., Jones, V. R., & Dugger, W. E. (2015). Status of technology and engineering education in the United States: A fifth report of the findings from the states (2014-2015). *Technology and Engineering Teacher, 74*(7), 30–36.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: The National Academies Press.

National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press.

National Center for Education Statistics. (2018). *2017 NAEP mathematics and reading assessments: Highlighted results at grades 4 and 8 for the nation, states, and districts*.

Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Dept. of Education.

National Science Teachers Association. (2014). K-12 Science Standards Adoption. Retrieved from https://ngss.nsta.org/About.aspx.

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. (2013) *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2)*,* 224-240.

OECD (2016). *PISA 2015 results (Volume I): Excellence and equity in education*. Paris: PISA, OECD Publishing.

Pearson, P. D., Moje, E. B., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science*, *328*(5977), 459-463.

Philips, S. (1972). Participant structures and communicative competence: Warm Springs children in community and classroom. In C. Cazden, V. P. John & D. Hymes (Eds.) *Functions of language in the classroom* (370-393). New York: Teachers College Press.

Pogner, K. H. (2003). Writing and interacting in the discourse community of engineering. *Journal of Pragmatics, 35*(6), 855-867.

Rainey, E. C. (2017). Disciplinary literacy in English Language Arts: Exploring the social and problem-based nature of literary reading and reasoning. *Reading Research Quarterly*, *52*(1), 53–71.

Rogers, C., & Portsmore, M. (2004). Bringing engineering to elementary school. *Journal of STEM Education: Innovations and Research*, *5*(3/4), 17.

Rosenblatt, L. M. (1994). The transactional theory of reading and writing. In R. B. Ruddell, M. R. Ruddell, & H. Singer (Eds.), *Theoretical models and processes of reading* (1057-1092). Newark, DE: International Reading Association.

SAE International. (2017). *A World In Motion*. Retrieved from http://awim.sae.org/

Saldaña, J. (2015). *The coding manual for qualitative researchers*. London: Sage.

Schleppegrell, M. J. (2004). *The language of schooling: A functional linguistics perspective*. Mahwah, NJ: Lawrence Erlbaum Associates.

Selzer, J. (1983). The composing processes of an engineer. *College Composition and Communication*, *34*(2), 178-187

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review*, *78*(1), 40-59.

Shanahan, C., Shanahan, T., & Misischia, C. (2011). Analysis of expert readers in three disciplines: History, mathematics, and chemistry. *Journal of Literacy Research*, *43*(4), 393–429.

Snow, C. E., & Sweet, A. P. (2003). *Rethinking reading comprehension. Solving problems in the teaching of literacy*. New York: Guilford Publications.

Snow, C., & Ucelli. P. (2009). The challenge of academic language. In D. Olson & N. Torrance (Eds.), *The Cambridge handbook of literacy* (112–133). Cambridge, MA: Cambridge University Press.

Street, B.V. (1984). *Literacy in theory and practice.* New York: Cambridge University Press.

Suchman, L. (2000). Embodied practices of engineering work. *Mind, Culture, and Activity, 7*(1-2), 4-18.

Tenopir, C., and King, D. W. (2004). *Communication patterns of engineers*. Hoboken, NJ: Wiley.

Toulmin, S. E. (2003). *The uses of argument: Updated edition* (2nd ed.). Cambridge: Cambridge University Press.

Vygotsky, L. (1986). *Thought and Language*. (A. Kozulin, Trans.). Cambridge, MA: MIT Press.

Vygotsky, L. (1978). *Mind in Society: The development of higher psychological processes.* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Cambridge, MA: Harvard University Press.

Wilson, A. A., Smith, E., & Householder, D. L. (2014). Using disciplinary literacies to enhance adolescents' engineering design activity. *Journal of Adolescent & Adult Literacy, 57*(8), 676-686.

Wilson-Lopez, A., & Minichiello, A. (2017). Disciplinary literacy in engineering. *Journal of Adolescent & Adult Literacy, 61*(1), 7-14.

Wineburg, S. S. (1991). Historical problem solving: A study of the cognitive processes used in the evaluation of documentary and pictorial evidence. *Journal of Educational Psychology*, *83*(1), 73–87.

Wineburg, S. S. (1998). Reading Abraham Lincoln: An expert/expert study in the interpretation of historical texts. *Cognitive Science*, *22*(3), 319–346.

Winsor, D. A. (1989). An engineer's writing and the corporate construction of knowledge. *Written Communication*, *6*(3), 270-285.

Winsor, D. (1990). Engineering writing/writing engineering. *College Composition and Communication, 41*, 58-70.

Yaşar, Ş. E., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education*, *95*(3), 205–216.

Yore, L. D., Hand, B. M., & Florence, M. K. (2004). Scientists' views of science, models of writing, and science writing practices. *Journal of Research in Science Teaching*, *41*(4), 338-369.