Professional Development for Secondary Science Teachers to Improve Engineering Knowledge, Pedagogy, and Career Advisement

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Professional Development for Secondary Science Teachers to Improve Engineering Knowledge, Pedagogy, and Career Advisement

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This quasi-experimental, mixed-methods observational study reports the design and implementation of an NGSS-aligned engineering workshop series for middle and high school educators focused on the science and engineering practices. The workshop structure and data analysis were based on the interconnected model for professional growth and supported by the situated learning and knowledge integration perspectives on cognition. University-based science, engineering, and science education faculty developed two workshop series in 1) electrical engineering and physics and 2) biotechnology and biology. Each series provided teachers with instruction in the engineering design process, science-engineering integration, and engineering career advisement. In each workshop, teachers engaged in science content-specific engineering activities that were designed to simulate the secondary classroom experience.

Science teachers (n=32) voluntarily participated in the workshops and completed pre- and post-workshop surveys. Comparisons of means indicated teachers reported statistically large improvements in their ability to: 1) use engineering activities in the classroom successfully, 2) increase student interest in engineering, 3) help students apply engineering to real-world situations, and 4) advise students on different engineering disciplines and careers, as well as how to prepare students for engineering before college. Pre- and post-workshop interviews with six of these teachers revealed an expansion of teachers’ perceived value of engineering in science and an increased confidence and ability to incorporate engineering and provide guidance to students interested in pursuing a future in engineering. Teachers also expressed their continuing concerns related to the school environment regarding engineering and science alignment.

The results from this study demonstrate that a university-based professional development workshop series is an effective intervention to improve the engineering knowledge and skills of secondary science educators, ultimately increasing NGSS adoption in science classrooms. Professional development programs such as this can serve as the foundation for increasing student exposure to engineering and interest in engineering careers.
Dedication Page

To my parents, for empowering me with a desire to learn and an appreciation of the natural world. I know that you share in my pride in this achievement, as you deserve to.

To my husband, Sean, for your continuous love, support, and encouragement while I pursued this accomplishment. I appreciate all that you have done to enable me to complete this goal.

To my children, Hadley and Colton, I hope as parents we inspire you to be lifelong learners, to commit to what is important to you, and to pursue a sense of accomplishment.

For Teri, Beth, and JoAnn, who were role models in teaching and motherhood. The culmination of this project has given me reason to reflect on the last eight and a half years. I have brought two amazing people into this world but said goodbye to these three lovely ladies. They will always be missed but their friendship and example will forever have an impact on me.
Table of Contents

ABSTRACT .......................................................................................................................... iii
DEDICATION PAGE ........................................................................................................... iv
LIST OF FIGURES .............................................................................................................. vii
LIST OF TABLES ............................................................................................................... ix
ACKNOWLEDGEMENTS ................................................................................................... x
CHAPTER 1 ......................................................................................................................... 1

INTRODUCTION ................................................................................................................. 1
  1.1 RATIONALE ............................................................................................................... 1
  1.2 RESEARCH QUESTIONS ............................................................................................ 2
  1.3 ENGINEERING IN SCIENCE INSTRUCTION ............................................................ 2
  1.4 STATUS OF ENGINEERING POST-SECONDARY STUDY AND CAREERS ............. 3
  1.5 OVERVIEW OF THESIS ............................................................................................ 4

CHAPTER 2 ......................................................................................................................... 5

LITERATURE REVIEW ....................................................................................................... 5
  2.1 INTRODUCTION ........................................................................................................... 5
  2.2 MODERN SCIENCE EDUCATION REFORM ............................................................. 5
      Motivation for modern reform. .................................................................................... 5
      Engineering in the Next Generation Science Standards. ......................................... 6
      Gaps in present day science instruction. ................................................................. 8
  2.3 HISTORICAL OVERVIEW OF U.S. SCIENCE EDUCATION REFORM ............... 8
      The Committee of Ten and Committee on College Entrance Requirements (1892-1899).... 9
      Early to mid-20th century science education reform. ............................................. 9
      Late 20th century science education reform. ........................................................... 9
      Science education reforms in the early 21st century. .............................................. 10
  2.4 PRINCIPLES OF ENGINEERING EDUCATION ......................................................... 11
      Engineering literacy ............................................................................................... 11
      Pedagogical content knowledge in engineering. ..................................................... 12
      Engineering career advisement ............................................................................. 12
  2.5 SCIENCE TEACHER PROFESSIONAL DEVELOPMENT ......................................... 13
      Assessing professional development ..................................................................... 14
      Effective professional development ....................................................................... 14
      Content focus ....................................................................................................... 14
      Coherence ............................................................................................................. 15
      Participant collaboration ..................................................................................... 15
      Sustained duration .............................................................................................. 16
      Modeling and engagement .................................................................................. 16
      Professional development in engineering education. ........................................... 16
      Authentic engineering design experience. ........................................................... 17
      Support from engineering professionals ............................................................. 17
      Connection to science content. .......................................................................... 18
  2.6 CONCEPTUAL FRAMEWORK: INTEGRATED MODEL OF ENGINEERING PEDAGOGICAL
      GROWTH ...................................................................................................................... 18
      Interconnected model of professional growth ..................................................... 19
      Situated learning perspective and social cognition ............................................. 19
Knowledge integration perspective ...................................................................................................................... 20
Self-efficacy theory ........................................................................................................................................... 21

CHAPTER 3 ......................................................................................................................................................... 22
METHODOLOGY .................................................................................................................................................. 22
3.1 INTRODUCTION ........................................................................................................................................ 22
3.2 RESEARCH DESIGN .................................................................................................................................. 22
3.3 CONTEXT ................................................................................................................................................... 23
3.4 PARTICIPANTS ......................................................................................................................................... 25
3.5 PRELIMINARY DATA INFORMING WORKSHOP DESIGN ......................................................................... 28
3.6 WORKSHOP STRUCTURE .......................................................................................................................... 29
   Contextual factors ........................................................................................................................................ 30
   Refining and building upon prior professional development models .................................................... 30
   Session activities ......................................................................................................................................... 30
      Electrical Engineering Workshop .............................................................................................................. 32
      Biological Engineering Workshop ............................................................................................................. 34
3.7 QUANTITATIVE METHODS ....................................................................................................................... 35
   Measures and instruments ............................................................................................................................. 35
   Data analysis ................................................................................................................................................. 35
3.8 QUALITATIVE METHODS ........................................................................................................................... 36
   Semi-structured interview protocol ................................................................................................................ 36
   Coding techniques ........................................................................................................................................ 36
   Reliability .................................................................................................................................................. 37

CHAPTER 4 ......................................................................................................................................................... 38
RESULTS ............................................................................................................................................................. 38
4.1 INTRODUCTION ........................................................................................................................................ 38
4.2 QUANTITATIVE RESULTS .......................................................................................................................... 38
   Overall survey results ................................................................................................................................. 38
   Exploratory factor analysis and thematic comparisons .............................................................................. 41
4.3 PROFILES OF INTERVIEWED TEACHERS ........................................................................................... 42
   Pedro ............................................................................................................................................................ 42
   Joseph .......................................................................................................................................................... 42
   Jack ............................................................................................................................................................. 42
   Lydia ........................................................................................................................................................... 42
   Sophie ......................................................................................................................................................... 43
   Richard ....................................................................................................................................................... 43
4.4 QUALITATIVE FINDINGS ............................................................................................................................. 43
   Pre-workshop vision of engineering ............................................................................................................. 43
      Definition of engineering .......................................................................................................................... 44
      Familiarity with NYSSLS .......................................................................................................................... 45
   Motivation to integrate engineering instruction ......................................................................................... 47
      Value of engineering in the science classroom ......................................................................................... 48
      NYSSLS implementation ........................................................................................................................... 53
   Teaching engineering confidence .................................................................................................................. 56
      Structure and influence of workshop ....................................................................................................... 57
      Implementation in science courses ............................................................................................................. 66
   Encouraging engineering futures ................................................................................................................ 79
List of Figures

Figure 1. NGSS structure and impacts on teaching and learning science ........................................ 8
Figure 2. Integrated model of pedagogical growth sequence in engineering education ............... 21
Figure 3. Emergent themes in pre- and post-workshop interviews. .............................................. 44
Figure 4. Theme 1: Pre-workshop vision of engineering. .............................................................. 44
Figure 5. Theme 2: Motivation to integrate engineering in science instruction ......................... 48
Figure 6. Theme 3: Teacher engineering confidence ................................................................. 57
Figure 7. Theme 4: Encouraging engineering futures ................................................................. 57
Figure 8. Theme 5: Obstacles to integrating engineering .............................................................. 79
Figure 9. Analytical framework of engineering professional development and teacher professional growth ........................................................................................................ 89
Figure 10. Summary of implications of study findings on various stakeholders ....................... 93
List of Tables

Table 1. NGSS Middle & High School Engineering Standards ..................................................... 7
Table 2. Workshop Alignment to High Quality Professional Development ............................. 24
Table 3. Workshop Participant Teaching Experience ................................................................. 25
Table 4. Teacher Interview Participants ................................................................................... 27
Table 5. Science Teacher Responses to Engineering Teaching Efficacy Survey ................... 29
Table 6. Workshop Activities with Sample NGSS Alignment ............................................... 31
Table 7. Engineering Professional Development Survey Results ........................................... 40
Table 8. Exploratory Factor Analysis of Thematic Constructs .............................................. 41
Table 9. Convergent Parallel Summary of Quantitative Results and Qualitative Findings .... 86
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1.1 Rationale

Science education in the U.S. is in the midst of major reform. The *Next Generation Science Standards* (NGSS), released in 2013, aim to improve K-12 science education through a renewed focus on scientific and engineering practices intertwined with recurring conceptual themes across the sciences (NGSS Lead States, 2013). The standards are based upon the National Research Council’s *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2012). Ultimately, the goal of NGSS is to empower all students to participate in public science discourse, be critical consumers of scientific information, and have the skills to pursue careers in the 21st century, particularly those in science, technology, and engineering (NRC, 2012). As an increasing number of states adopt NGSS, or a variation of them, there is mounting pressure to inform and prepare science educators for the impending changes in expectations, curriculum, and assessment. The adoption of NGSS presents a particularly novel challenge for the field of science education – integrating engineering practices with science knowledge and skills.

There are significant challenges as states transition their science standards to align with NGSS. Historically, attempts at educational reform have often been unsuccessful in terms of the rate and scope of change. A number of factors contributed to these issues, such as lack of involvement of educators in policy-making, insufficient professional development and support for teachers, stakeholder resistance to change, inconsistency of implementation, and inadequate time and curricular resources (Anderson & Helms, 2001; Fullan & Miles, 1992). In this recent reform effort, science teachers have been likely to be inadequately prepared and lack confidence to teach the engineering components of the standards, leading to avoidance or misrepresentation of the engineering practices in the classroom (Purzer, Moore, Baker, & Berland, 2014). These potential pitfalls must be addressed to encourage widespread adoption and implementation of NGSS in science classrooms throughout the U.S.

Productive and accessible science teacher professional development, specifically in the field of engineering education, is necessary for realizing the vision of NGSS. Effective professional development can increase the likelihood that teachers will follow through on implementation of this reform and ultimately influence student achievement in science and engineering (Darling-Hammond, Hyler, & Gardner, 2017; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). In response to this critical need, this research examined the influence of an engineering professional development experience on science teachers’ perceptions of engineering in the science classroom as well as their self-assessed ability to teach engineering and support students in the pursuit of engineering futures. In addition, this study identified potential obstacles these teachers faced or anticipated when implementing engineering design lessons in their science courses in order to inform future research efforts. The existing research is generally deficient in reporting on the
attitudes and approaches of science teachers concerning the inclusion of engineering design and career advisement in their courses.

1.2 Research Questions

Following their involvement in a multi-session professional development workshop in engineering practices for science educators, this convergent parallel, mixed methods study investigated three questions about the impact of this professional development experience on teachers and their beliefs regarding the integration of engineering in their science courses:

1. How does professional development in engineering education affect secondary school science teachers’ beliefs about the value of using engineering design to support science learning?
2. How does professional development in engineering education affect secondary school science teachers’ self-efficacy regarding teaching engineering in their science courses and providing advisement for engineering careers?
3. What obstacles do science teachers identify during the implementation of engineering practices in their science classes?

The professional development workshops were designed to prepare secondary science teachers to integrate engineering into their science course content based on newly adopted state science education standards. This was accomplished through instruction on the engineering design process and engagement in engineering experiences with support from university engineering and science education instructors. Using a convergent mixed methods approach, this study evaluated teacher participants’ beliefs about the value of engineering in science education and their perceived self-efficacy in teaching engineering design before and after their experiences in the course. Previous studies have identified these factors as influential in teacher implementation of reform efforts in the classroom (Birman, Desimone, Porter, & Garet, 2000; Blank, de las Alas, & Smith, 2007; Knapp, 2003). In addition, this study identified teachers’ concerns about using engineering in science education following their involvement in the course. The intention of this component of the study was to inform further research on eliminating these obstacles for future science teachers implementing engineering in their instruction.

1.3 Engineering in Science Instruction

NGSS explicitly integrate engineering instruction into K-12 science curricula in the U.S. (NGSS Lead States, 2013). The call for this reform was based on decades of research and reports illustrating the value of engineering in developing students’ science knowledge and preparing students to contribute to the nation’s future economic and environmental stability and technological growth (American Association for the Advancement of Science [AAAS], 1990; NRC, 2009, 2012). Both science and engineering are central to the modern human experience and a basic awareness of each is necessary for making informed personal and public decisions. The need for a scientifically and technologically literate citizenry motivated the authoring committee of *A Framework for K-12 Science Education* to identify engineering specifically as a critical component of effective science instruction. The inclusion of the engineering performance
expectations at every instructional level of science ensures that all students are exposed to the engineering design process and engaged in engineering practices (NRC, 2012).

The synthesis of science and engineering instruction within NGSS provides a context for students to apply their developing science knowledge in practical and relevant real-world scenarios using engineering to enhance learning in both domains of understanding. There is ample evidence to support the positive impacts of embedding engineering instruction within the science curriculum (NRC, 2012). Research has shown that employing the engineering design protocol to support science instruction can improve student understanding of the related science content and improve retention of science knowledge (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Guzey, Ring-Whalen, Harwell, & Peralta, 2019; McGowan, Ventura, & Bell, 2017; Mehalik, Doppelt, & Schuun, 2008). Additionally, engaging students in certain types of engineering tasks in the science classroom has been shown to diminish the achievement gap for traditionally underrepresented groups of students, including special education students, students of low socioeconomic status, and Hispanic and Black students (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Mehalik et al., 2008). Evidence also supports the use of engineering in the science classroom to increase student interest in associated fields as well as provide critical problem-solving skills and technological literacy essential for navigating the modern world (Guzey et al., 2019; McGowan et al., 2017; NRC, 2009).

1.4 Status of Engineering Post-Secondary Study and Careers

For years, reports such as A Framework for K-12 Science Education (NRC, 2012), Project 2061 (AAAS, 1990, 1994), and Rising Above the Gathering Storm (National Academy of Sciences, 2007), have established the need for science education reform to maintain a productive and competitive U.S. workforce. The primary objective of this latest vision of science education is to empower all students in the U.S. to develop the scientific reasoning and knowledge needed to contribute positively to modern society. It is anticipated that in providing a strong foundation of knowledge and experience in science and engineering, more students will also be inspired to pursue post-secondary education and careers in related fields (National Academy of Sciences, 2007; NRC, 2012).

Increasing student enrollment and retention in university engineering majors is necessary to supply the modern workforce with qualified, skilled individuals to fill new and developing jobs. Progress has been made in recent years to promote post-secondary study in engineering but gaps persist. Between 2007-2015, the number of engineering degrees awarded in the U.S. increased (Yoder, 2016). Upward trends in the completion of engineering degrees by women, Black and African American, and Hispanic students were also observed during the same period (Roy, 2019; Yoder, 2016). Despite the growing diversity in engineering fields of study, the aforementioned groups continue to be underrepresented in terms of degree completion (Committee on Equal Opportunities in Science and Engineering, 2017; Roy, 2019). By incorporating engineering standards and practices into the K-12 science curriculum, NGSS aims to increase exposure and accessibility to engineering for all students (NRC, 2012).

It is anticipated that the total number of U.S. engineering employment positions will increase by 8.3% between 2016-2026 to 1.82 million U.S. engineering jobs (United States Bureau of Labor Statistics, 2018). In accounting for these new jobs, as well as vacancies created by individuals leaving the field or workforce, an expected 1.265 million engineers will be needed to fill the available job openings in the ten years preceding 2026 (Sargent, 2017). Disparities in the
distribution of women and minorities in engineering persisted from college to the workforce. In 2015, women accounted for 15% of the engineering workforce and Hispanic and Black individuals occupied less than 11% of the total positions in all fields of science and engineering (National Science Board, 2018). Pre-college innovations in authentic engineering education may diminish the achievement gap in STEM learning and improve diversity in engineering fields.

1.5 Overview of Thesis

The remainder of this thesis presents the background, research methodologies, findings, and discussion of critical themes that emerged from the investigation of the impact of engineering professional development on science teachers’ self-efficacy in engineering instruction and career advisement. Chapter 2 summarizes a review of the relevant literature concerning science education reform, including NGSS. Also discussed are the current research on effective professional development in science and engineering teaching and a conceptual framework based on several teacher knowledge growth theories. Chapter 3 presents the detailed methodology for data collection in this parallel convergent mixed methods study. Details regarding the workshop structure and teacher participants are also presented. The quantitative results and qualitative findings are discussed in Chapter 4. Statistical analysis of the survey responses and predominant emergent themes from teacher interviews are presented. Finally, Chapter 5 includes a discussion of the impacts and implications of this research. Limitations and suggestions for further research are also explored in this chapter.
Chapter 2

Literature Review

2.1 Introduction

In response to mounting concern regarding the ability of the U.S. to maintain a position of global leadership in technology and innovation, the nation’s K-12 science education framework is in the process of change. Fear of the related economic implications and evidence that students have been unprepared have motivated this change, which is intended to develop a qualified and motivated workforce to fill the job vacancies that exist today and are anticipated in the near future. At the forefront of this initiative is an emphasis on the integration of the process of engineering within the practices and content of science, for the purpose of supporting student understanding and awareness of both science and engineering (NRC, 2012). By mid-2018, 40 states and the District of Columbia had modified their science standards based on *A Framework for K-12 Science Education*, the foundation of NGSS (Achieve, Inc., 2019). The adoption of NGSS in these states presents a novel challenge for science teachers who are generally not prepared with the knowledge and skills to teach engineering effectively. It is imperative for the success of this reform that high-quality, accessible professional development specifically focused on engineering instruction is offered to teachers to ensure the integrity of NGSS alignment.

This literature review chapter characterizes the basis for the current reform in science education and details the format and components of NGSS. In Section 2.2, an overview of modern science education reform and the standard of expectation for engineering instruction are discussed. Section 2.3 presents an historical overview of science education reforms dating back to the late nineteenth century. Principles of engineering education reform are detailed in Section 2.4. The existing research on effective science and engineering teacher professional development is presented in Section 2.5 as the model for the treatment in this study. In Section 2.6, a conceptual framework for analysis is described. Section 2.7 briefly summarizes the main points of the chapter.

2.2 Modern Science Education Reform

Motivation for modern reform.
A number of factors led to the development of the Next Generation Science Standards, the most recent standards reform in U.S. science education. Concerns about American high school student performance on standardized science assessments and the continuing shift in the needs of U.S. employers for qualified and skilled workers were the predominant driving forces behind the development of these new standards (NRC, 2012). The modern workforce requires a new set of problem solving and critical thinking skills that until now have not been well-supported or encouraged by previous science and mathematics education standards. Currently, the U.S. education system is producing an insufficient pool of qualified candidates to fill the continually increasing number of available STEM jobs (President’s Council of Advisors on Science and Technology [PCAST], 2012).
The science achievement of American students has raised concerns about the efficacy of previous approaches to science education and spawned the current movement for reform (NGSS Lead States, 2013). Among 2012 high school graduates taking the ACT exam, 69% failed to meet benchmarks for college readiness in science. Even among the subset of students completing three or more years of high school science coursework, 67% failed to meet the organization’s benchmarks for science competency (ACT, 2012). Those statistics have improved somewhat in the years following. Based on the ACT results of high school students graduating in 2018, 64% of students failed to meet the college readiness benchmarks in science and of those students completing a core curriculum of science, 57% failed to meet the ACT science benchmarks for college readiness (ACT, 2018). Considering the global nature of today’s economy, it is particularly concerning that U.S. students continue to perform below many other developed countries in high school science. The most recent Program for International Student Assessment results ranked American 15-year-olds 25th in science literacy, a trend that has been consistent for several years (Organization for Economic Cooperation and Development [OECD], 2012, 2016).

The changing U.S. and global economies were also driving forces for current education reform. In recent decades, American economic growth has become increasingly dependent on innovation (United States Congress Joint Economic Committee [USCJEC], 2012). In light of this, it is imperative that our workforce be trained with the science literacy and skills necessary to design and refine solutions to challenges confronting our society today and into the future. As of yet, the demand for individuals needed to fill these positions has not been met with a supply of employees qualified in STEM fields. In 2012, it was forecast that an additional one million STEM professionals would be needed to fill jobs by 2022 (PCAST, 2012). In the ten years prior to the release of the NGSS, jobs in STEM-related fields were growing at a rate three times that of non-STEM jobs (NGSS Lead States, 2013). At the same time, only 18% of bachelor’s degrees awarded in the U.S. were in STEM fields and engineering students made up only 6% of undergraduate majors (National Academy of Sciences, 2007; USCJEC, 2012). One of the goals of NGSS is to motivate more students to pursue and persist in STEM fields through more positive and engaging school science experiences (NRC, 2012).

**Engineering in the Next Generation Science Standards.**

At the forefront of the NGSS mission is the integration of engineering practices within the science content and skills standards. This aims to deepen students’ understanding of science through engagement in both science and engineering activities (Moore et al., 2014; NRC, 2012). Integration of engineering design in the science classroom has been shown to facilitate the development of science knowledge as well as logical thinking and communication skills. Applying the design process in the context of science encourages students to view systems and processes both holistically and discretely to foster deeper understanding of science content (Brophy, Klein, Portsmore, & Rogers, 2008).

The Framework for K-12 Science Education (NRC, 2012), which is the foundation for NGSS, characterizes engineering as, “a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants” (p. 202). NGSS identifies three core engineering design principles to be emphasized throughout K-12 science instruction. First, curriculum should be framed to provide students with opportunities to identify problems and define related limitations and criteria for solutions. Second, students should be encouraged to generate and evaluate a variety of solutions to identified problems. Finally, curricula should enable students to optimize solutions through analysis of the value and costs associated with proposed solutions to
problems. For example, one NGSS high school life science performance expectation (HS-LS2-7) requires that students “design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity” (NGSS Lead States, 2013, p. 108). The complete NGSS standards for secondary (grades 6-12) engineering are summarized in Table 1.

Table 1. *NGSS Middle & High School Engineering Standards* (NGSS Lead States, 2013)

<table>
<thead>
<tr>
<th>Middle School Engineering Design Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MS-ETS1-1.</strong> Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.</td>
</tr>
<tr>
<td><strong>MS-ETS1-2.</strong> Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</td>
</tr>
<tr>
<td><strong>MS-ETS1-3.</strong> Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.</td>
</tr>
<tr>
<td><strong>MS-ETS1-4.</strong> Develop a model to generate data for iterative testing and modification of a proposed object, tool or process such that an optimal design can be achieved.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High School Engineering Design Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HS-ETS1-1.</strong> Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.</td>
</tr>
<tr>
<td><strong>HS-ETS1-2.</strong> Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.</td>
</tr>
<tr>
<td><strong>HS-ETS1-3.</strong> Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible societal, cultural, and environmental impacts.</td>
</tr>
<tr>
<td><strong>HS-ETS1-4.</strong> Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.</td>
</tr>
</tbody>
</table>

The Next Generation Science Standards aim to bridge the existing gap between K-12 science classroom experiences and the true nature of science in society and the workplace (NGSS Lead States, 2013). Consequently, central to the structure of the NGSS is an emphasis on science and engineering practices (NGSS Lead States, 2013). Additionally, the NGSS are designed around a unique three-dimensional approach. Dimension one focuses on the science and engineering practices that scientists and engineers employ in developing knowledge and solving problems. The second dimension identifies the crosscutting concepts, or themes, that are reflected throughout all domains of science. Dimension three identifies essential scientific knowledge required for basic literacy in science. This organizational shift away from conventional content-driven standards is meant to provide a more cohesive K-12 science experience and ensure that all students complete high school with the basic science and engineering literacy required for the 21st century (NRC, 2012). This educational strategy is intended to improve motivation and performance in science, leading to more diversified accessibility to STEM study and careers (Figure 1).
Gaps in present day science instruction.
There are a number of ways the NGSS deviate from previous visions of science education in state science standards and curricula throughout the U.S. The inclusion of engineering within the science standards is a significant addition to earlier versions of K-12 science. Previous science standards rarely made reference to engineering. An analysis of science education standards throughout the U.S. prior to the release of the NGSS indicated that only 12 states identified specific applications of engineering principles within their state science curriculum (Carr, Bennett, & Strobel, 2012).

In an attempt to move away from the typical classroom approach to science as a routine process through teaching the “scientific method,” central to the structure of the NGSS is an emphasis on science practices (NGSS Lead States, 2013). The term practice is used specifically to denote the active engagement of students in lessons which draw upon the interconnectedness of science as both a body of knowledge and a process of acquiring and applying that knowledge (Ford, 2015; NRC, 2012). Each set of performance expectations requires students to utilize specific content knowledge to accomplish the practices in order to demonstrate their scientific literacy (NGSS Lead States, 2013).

2.3 Historical Overview of U.S. Science Education Reform

While the presentation of the NGSS is novel, many of the central themes outlined in the Framework for K-12 Science Education, such as promoting scientific literacy, emphasizing the process of science, and fostering conceptual understanding, have been emphasized in previous incarnations of American science education (DeBoer, 1991; NRC, 2012). Unique to this reform movement is the emphasis on the inclusion of engineering as part of a robust K-12 science education experience (NRC, 2012). To appreciate the significance of this latest reform effort, it is worth reviewing a brief history of U.S. science education.
The Committee of Ten and Committee on College Entrance Requirements (1892-1899). The National Educational Association (NEA) convened the Committee of Ten in 1892 to standardize the American elementary and secondary school experience. The study of science was established as requisite coursework in addition to the classic Latin and Greek curricula that had been the prior focus of schools. The Committee members considered the value of science training in developing individuals’ inductive reasoning skills through thorough observation and analysis of the natural world (DeBoer, 2000; NEA, 1894). The importance of laboratory work and the experiential nature of science learning were more clearly defined in the report of the Committee on College Entrance Requirements, which established much of the foundation of the modern American K-12 school system in 1899 (NEA, 1899). At this early stage of its existence, the mission of science education was to develop students’ intellectual abilities and the habits of mind intended to benefit individuals in other contexts (DeBoer, 2000).

Early to mid-20th century science education reform. Several decades later, the Commission on the Reorganization of Secondary Education initiated the transformation of the objectives of science coursework, which are reflected in even the latest mission to reform science education in the U.S. (DeBoer, 2000). The Commission emphasized the importance of teaching science practices in the context of every science course and recommended that curricula and instruction in all areas of science should relate content material to a student’s life outside of the classroom – in the home, community, and industry (NEA, 1920). Around this time, The National Engineering Societies commissioned a report on the status of engineering education in the United States. Several universities had established dedicated schools for the study of engineering but were struggling with low student persistence. The report emphasized the nature of engineering as an applied science and urged for college entrance exams, and the preparatory high school science coursework, to emphasize the development of skills instead of learning scientific facts (Mann, 1918).

Through the next several decades, the National Society for the Study of Education played a prominent role in shaping U.S. science education. The committee continued to emphasize the value of science instruction for the betterment of society by providing individuals with the knowledge and skills necessary to participate in an increasingly technologically dependent democracy (DeBoer, 2000). Starting in the late 1950s, facilitated predominantly by university scientists, programs such as the Physical Sciences Study Committee, ChemStudy, and the Biological Sciences Curriculum Study attempted to define the standards for K-12 instruction in their respective fields (Atkin & Black, 2003). Each of the curriculum projects emphasized the experiential process of learning science over the use of textbooks and rote memorization. With the support of the National Science Foundation (NSF), these university-based committees began to disseminate curriculum resources through teacher training (Elmore & McLaughlin, 1988).

Late 20th century science education reform. Despite the investment in the NSF curriculum projects, there was growing concern that American students were not prepared to compete in a global economy dependent on innovation. In 1983, A Nation at Risk: The Imperative for Educational Reform was released; the report declared the importance of improving the scientific and technological literacy of our nation’s youth as a result of the increasing pervasiveness of technology in health care, food processing, industry, and the military, among other aspects of daily life (United States National Commission on Excellence in Education [USNCEE], 1983). The call for improving our citizen’s science literacy was again
Publicized in 1990 with the AAAS release of *Project 2061: Science for All Americans*. In this report, the concern was more global; the issues facing our world – acid rain, loss in biodiversity, exponential population growth – all required a basic awareness of science, mathematics, and technology for all global citizens. According to the report, the majority of the American public was still not sufficiently science literate. The *Project 2061* report recommended that when teaching science, teachers must allow students the opportunity to engage in the behaviors of a scientist by investigating the world around them, collecting and interpreting data, and communicating their findings and related evidence to colleagues. The elements of the design process are detailed in the report, establishing the relationship between science content knowledge and engineering in contributing to the development and improvement of technology (AAAS, 1990). In a companion to the report, *Benchmarks for Science Literacy*, specific learning objectives characterized the proposed essence of the K-12 science learning experience. Intended as a framework for curriculum development, the *Benchmarks* attempted to reduce the expansiveness of existing science curricula in order to emphasize the central themes of science and the interconnectedness of science, mathematics, and technology. Missing from this framework was the inclusion of the engineering process as part of the proposed science learning experience (AAAS, 1994).

Growing concern about the state of U.S. science education and the scientific literacy of Americans prompted the release of the *National Science Education Standards* in 1996 (NRC, 1996). Inspired by reports such as *A Nation at Risk* (USNCEE, 1983) and *Project 2061: Science for All Americans* (AAAS, 1990), the *National Science Education Standards* was an attempt to formalize science education throughout the U.S. and achieve the goals outlined in these previously released national reports. The voluntary standards were meant to provide the framework for adopting agencies to provide a more engaging science learning experience for K-12 students, thereby empowering them to contribute productively to society through responsible decision-making and employment in science-related fields. Similar to the NGSS, the *National Science Education Standards* connected science content through several overarching scientific themes and encouraged student engagement in scientific inquiry. The science practices were emphasized throughout the *National Science Education Standards* but the document does not explicitly acknowledge the engineering design process in the science classroom. Engineering was mentioned only tangentially in the *National Science Education Standards* acknowledging that scientists and engineers often cooperate in developing technology and innovation (NRC, 1996). Motivated by these reports, New York State attempted to introduce a high school capstone course titled, *Principles of Engineering*, in the mid-1990s. Intended for high school students in their junior or senior year and taught by technology teachers, the course was designed to unify science, mathematics, technology, and engineering while stimulating student interest and developing technological literacy. The course syllabus identified instructional objectives for engineering design, modeling, systems, optimization, technology in society, and ethics in engineering (New York State Education Department, 1995). Without a standardized adoption or assessment protocol, the offering failed to develop salience state-wide (Dettelis, 2010).

**Science education reforms in the early 21st century.**

By 2003, nearly every state had adopted state science standards, many of which were based on the *National Science Education Standards*. Local implementation of *National Science Education Standards*-aligned curriculum and assessments in classrooms was limited, in part due to the limited availability of aligned curricular materials, inadequate teacher professional development opportunities, and inconsistent standards of accountability for implementation (NRC, 2003).
Continuing concerns about the performance of U.S. students on benchmarked exams and growing economic reliance on technology and science-related industries was the impetus for yet another call for action in 2007. The National Academies released a highly cited report, *Rising Above the Gathering Storm*, which declared that our national economy, security, environmental stability, and standard of living were at risk and radical changes in education and science research were necessary to improve the skills and knowledge of our citizens in the modern world. The report also placed significant emphasis on the expanding role of engineering in the global economy and identified value in expanding engineering education in K-12 programs. With intentions to increase the motivation and ability of U.S. students to pursue careers in science and engineering, the report recommended efforts to bolster the recruitment and preparation of highly qualified teachers in science and mathematics, improved quality and accessibility of training opportunities for practicing teachers, and the development of a repository of vetted teaching materials to be made available to teachers throughout the country (National Academy of Sciences, 2007).

As the global economy has shifted to rely increasingly on innovation of technology through engineering, it is necessary that the U.S. education system adapt accordingly. Concerns regarding the preparation of a citizenry fit for the modern workforce has been mounting for decades, as evidenced by reports such as *A Nation at Risk* (UNNCEE, 1983), *Project 2061* (AAAS, 1990, 1994), and *Rising Above the Gathering Storm* (National Academy of Sciences, 2007). The culmination of this effort to align K-12 learning standards to the present economic needs of the nation is the *Next Generation Science Standards* (NGSS Lead States, 2013). NGSS are the first national science education standards to infuse engineering directly into the science classroom to ensure that students are prepared with the necessary knowledge and skills to successfully contribute to a technologically driven society (NRC, 2012).

### 2.4 Principles of Engineering Education

NGSS focuses on student engagement in the practices of science and engineering design. As it is characterized in the NGSS, the domain of engineering involves the development of solutions to address real-world problems (NGSS Lead States, 2013). The inclusion of engineering in the domain of science is an innovative component of this reform movement meant to develop problem solving and critical thinking skills in students and support student learning of science content knowledge (Brophy et al., 2008).

**Engineering literacy.**
The American Society for Engineering Education (ASEE) standards for teacher preparation in engineering education focus on three key domains of engineering literacy for both teachers and their students: 1) engineering design, 2) engineering careers, and 3) engineering and society. The standards aim to identify the fundamental principles of engineering knowledge and practice. As described in the standards document, engineering education must be founded on an understanding of the design process, with emphasis on optimizing solutions to work within constraints. In addition, literacy in engineering requires the development of problem solving, critical thinking, and communication skills. Engineering literacy also includes the awareness of engineering career opportunities, the educational requirements to attain work in those fields, and awareness of the influence of technology and society on each other (ASEE, 2014).
**Pedagogical content knowledge in engineering.**

For science teachers to be able to teach engineering effectively, more than just a basic literacy in engineering is required. For a teacher to influence student learning successfully, he or she must have not only subject matter knowledge but also skills to be able to impart that knowledge to students. Shulman (1986) described pedagogical content knowledge as the awareness of how to teach a subject to students. This includes the ability to identify and address common student misconceptions related to the subject matter and the use of idealized representations, examples, and explanations that elucidate subject matter for students. Pedagogical content knowledge describes a teacher’s awareness of the challenges associated with teaching specific subject matter to students and the ability to use specialized strategies to address these obstacles to increase student learning (Shulman, 1986). Effective engineering instruction integrated with science requires the development of entirely new domains of both engineering content knowledge and pedagogical content knowledge for science teachers.

The development of teachers’ engineering-specific pedagogical content knowledge is necessary to ensure students engage in authentic engineering experiences in the classroom. To develop students’ awareness of the engineering process, teachers must be able to differentiate between beginning and advanced student designers and target each students’ deficiencies with appropriate learning tasks. Effective engineering teaching provides ample opportunities for assessment and targeted support for students as they develop engineering proficiency (Crismond & Adams, 2012). In their synthesis of research on engineering pedagogical content knowledge, Crismond and Adams (2012) assembled a matrix of engineering design learning targets and suggested instructional strategies to facilitate student growth. For example, beginning engineering students often struggle to approach the iterative phase of design, testing, and revision with purpose, whereas more advanced designers critically evaluate prototypes to manipulate successful and unsuccessful design features in subsequent testing phases. To support student development with regard to iteration, teachers might structure student reflection in a storyboard format while encouraging risk-taking with emphasis on evaluation of design features (Crismond & Adams, 2012).

**Engineering career advisement.**

The academic experiences of students before college often influence their career aspirations and how they make choices to reach these goals. High school academic course selection is an important consideration in engineering admissions, since most schools of engineering typically require advanced science and mathematics coursework. Post-secondary success in engineering study has often been linked to precollege course preparation in advanced mathematics and science (May & Chubin, 2003; Tyson, 2011; Tyson, Lee, Borman, & Hanson, 2007; Wang, 2013), however, access to such courses has been inequitable in terms of ethnicity and socioeconomic status (Kelly & Sheppard, 2008, 2009, 2010, 2019; National Center for Science and Engineering Statistics, 2018; Padwa, Kelly, & Sheppard, 2019). Teachers may also be influenced by latent biases concerning which students are best suited for engineering (Nathan, Tran, Atwood, Prevost, & Phelps, 2010). In order to achieve the goal of a larger and more diversified engineering workforce, secondary science educators are well positioned to promote post-secondary engineering study and careers, particularly in terms of guiding students to select the appropriate coursework to have equitable access to this career choice. Science teacher professional development may be a means to achieve this goal.
Knowledge of the tasks involved in various engineering disciplines is another consideration in precollege career advisement, yet there has been limited research in this area. Both students and science teachers may have a lack of knowledge or misconceptions regarding the nature of specific engineering subdisciplines, for example, researchers have found confusion in how students differentiate among computing disciplines (Anthony, 2003) as well as weak understandings of engineering in general (Montfort, Brown, & Whritnour, 2013). Engineering career choice is often predicated upon whether students believe that choice is consistent with their personal identities and values (Kolmos, Mejlggaard, Haase, & Holgaard, 2013; Matusovich, Streveler, & Miller, 2010), therefore, it is important that students be able to differentiate what different engineering careers entail. Limited formal engineering career advisement typically occurs with school counselors (Gearns, Kelly, & Bugallo, 2018; Gibbons, Hirsch, Kimmel, Rockland, & Bloom, 2003), yet science teachers may be better positioned to influence students through informal conversations, encouragement, and classroom-based instructional strategies that occur throughout the STEM pipeline (Moore, 2006; Packard & Jeffers, 2013).

2.5 Science Teacher Professional Development

An integral component of successful education reform is teacher professional development. Past efforts to implement significant pedagogical or curricular changes in schools have experienced limited success, in part due to a lack of support and education provided to teachers (Fullan & Miles, 1992). Without sufficient knowledge of the reform expectations, confidence in their ability to apply reform practices in the classroom, and personal acceptance of the reform, it is unlikely that teachers will implement change in their classrooms (Haney, Czerniak, & Lumpe, 1996; Supovitz & Turner, 2000). It has been shown that teacher professional development is a critical component bridging the gap between policy dictating reform efforts and classroom practice and student learning (Knapp, 2003). Effective and accessible professional development in both engineering content and pedagogy for science teachers is imperative to the success of this latest reform effort.

Despite evidence to support the need for teacher training associated with pedagogical reform, opportunities for science teachers to learn about engineering is limited and many teachers do not have the awareness and ability to integrate engineering into their science courses. According to the results of the 2018 National Survey of Science and Mathematics Education, less one-third of K-12 science teachers had participated in any engineering-specific professional development. Additionally, teachers have had few opportunities to implement engineering in their classrooms. Of the middle school science teacher respondents, 61% admitted to rarely or never incorporating engineering or coding lessons into their course. Seventy percent of high school science teachers said the same. The majority of survey respondents lacked confidence in their ability to teach engineering, as only 43% of middle school science teachers and 33% of high school science teachers felt prepared (Banilower et al., 2018). The disparities between NGSS expectations and teacher capabilities concerning engineering education are likely to result in inadequate and inaccurate representations of the engineering design process in the science classroom as well as perpetuate the inequitable access to engineering for historically underrepresented students. Effective and accessible engineering training for in-service and pre-service science teachers is necessary to address these potential pitfalls during the implementation of the NGSS (Purzer et al., 2014).
Assessing professional development.
Professional development can be characterized by the extent to which the program influences teacher knowledge and skill, the degree of implementation in the classroom, and the effect on student learning (Darling-Hammond et al., 2017; Desimone, 2009; McHugh, Kelly, & Burghardt, 2018). A variety of qualitative and quantitative methods can be implemented in the evaluation of professional development experiences. A review of 25 mathematics and science teacher professional development programs from across the country identified commonly referenced means of measuring each of these variables. Many programs utilized a post-treatment survey instrument to assess teachers’ impressions of the value of the program, the program deficiencies, and their level of satisfaction with the professional development experience. Development of teacher content knowledge was typically measured by comparing teacher performance on pre- and post-intervention written assessments. Several professional development initiatives included long-term assessments of retention several months following the experience. The degree to which practices were implemented in the classroom was often evaluated by teacher self-reporting through a survey or interview. Several programs used classroom observations to evaluate implementation as well as student achievement. Often times, improvements to student achievement were evaluated with written student assessments with a comparison to a non-treatment group (Blank et al., 2007).

Effective professional development.
Recent research identified several key components of effective teacher professional development. High quality professional development tends to be focused on specific content or pedagogical content knowledge, is aligned with state or local standards and expectations, encourages collaboration between teachers, is sustained over time, and both models and engages teachers in the reform practice (Birman et al., 2000; Darling-Hammond et al., 2017; Guskey, 2003; Supovitz & Turner, 2000; Wilson, 2013).

Content focus.
One of the most frequently identified features of high-quality professional development that impacts student achievement is a content focus (Darling-Hammond et al., 2017). Teachers responded more positively and productively to professional development emphasizing the teaching of specific content over generalized professional development that was not related to their subject matter (Birman et al., 2000). In an extensive analysis of teacher-reported data following participation in a variety of professional development opportunities, researchers found a strong positive effect of content-focused professional development on teacher knowledge and skill, and a resulting positive impact on change in classroom pedagogy. Data were collected from survey responses of 1,027 mathematics and science teachers from 358 school districts across the U.S. that had participated in any type of professional development funded by the Eisenhower Professional Development Program (Garet, Porter, Desimone, Birman, & Yoon, 2001).

In an unrelated study of 44 secondary high school science teachers, the positive impact of content-focused professional development was again evident (Jeanpierre, Oberhauser, & Freeman, 2005). Teachers took part in an intensive two-week-long residence program to study the ecology of the monarch butterfly alongside biology professors, biology graduate students, a monarch scientist, other science educators, and high school students. The program consisted of daily presentations from the experts on ecology and science inquiry followed by classroom-appropriate activities with time allotted for reflection. Throughout the week, teams of participants and facilitators worked together on short field research projects related to monarch ecology designed
to demonstrate science process skills. Data were collected through teacher surveys, pre- and post-experience assessments on monarch butterfly knowledge, observations made by the investigators during the program, interviews and evaluations from program staff, and teacher case studies. Quantitative analysis showed significant gains for teachers in content knowledge. Interviews with teachers demonstrated their appreciation for the emphasis on content throughout the professional development experience and a high rate of application of both their content knowledge and science practice skills in the classroom following their participation (Jeanpierre et al., 2005).

**Coherence.**

Research has indicated that teacher investment in reform is based largely on the consistency with which the initiative goals align with other educational reforms being implemented (Guskey, 2003). In addition, teachers are more likely to enact change in their classrooms when the reform and associated professional development are aligned with their existing course standards and curriculum (Birman et al., 2000).

In a study of 454 Earth science educators involved in a professional development program for scientific inquiry, program coherence with teacher and student goals was identified as a significant positive factor in the efficacy of the professional development (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Teacher training was conducted at 28 different sites throughout the U.S. While the ultimate goal of the professional development experiences was the same between sites, there were variations in the format of presentation, activities, and length of professional development experience between programs. Data were collected from surveys of both professional development providers and teacher participants. Researchers found that the teachers who felt more prepared and were more likely to implement program strategies in their classrooms were those who participated in professional development that was closely aligned with their state or local standards and provided support to integrate the reform into their existing curricula. In addition, the investigators found that participants were more likely to make use of the program protocol in their classrooms when the professional development experience was aligned with other reform efforts being carried out in their own schools (Penuel et al., 2007).

**Participant collaboration.**

Frequently cited as a factor in effective teacher development is the opportunity for teacher collaboration. Opportunities for collegial interaction during teacher professional development allows participants to exchange ideas and strategies for teaching, reflect on their experiences in the classroom, and provide and receive feedback on their practice (Guskey, 2003). Survey data collected from the same large sample of mathematics and science teacher participants in the Eisenhower Professional Development Program discussed earlier identified collaboration as an integral feature of productive professional development. A three-year longitudinal study investigating the use of classroom technology following related professional development identified collective teacher participation during professional development as having a significant positive effect on classroom implementation (Desimone, Porter, Garet, Yoon, & Birman, 2002).

A study of the implementation of a significant reform effort to reorganize the middle school science program in one school district provided evidence of the value of teacher collaboration in professional development (Davis, 2003). The program required a transition to a more conceptual science curriculum in which major themes were repeated through instruction in multiple contexts and included the use of technology, engineering activities, and connections with other academic disciplines to support student learning of science content. Teachers were supported through a
multi-year adoption process as the school participated in a field test program of the new curriculum. They received release time and financial support for professional development opportunities conducted by the program developers and local university faculty. Researchers collected data during the final year of the curriculum field test through classroom and faculty meeting observations, interviews with teachers and students, and analysis of standards and curriculum materials. Teacher participants who were interviewed about their experiences placed high value on the structured collaborative opportunities where they could discuss problems they confronted during the reform and get feedback on how others resolved those same issues. One teacher cited the collaborative lesson planning she did with other teacher participants as essential to her success with the new program (Davis, 2003).

**Sustained duration.**
While no definitive time measure has been attributed to effective teacher professional development, research supports the implementation of experiences for a sustained duration. Long-term teacher learning programs are more likely to result in teacher change than short-term or single engagement experiences. Sustained multi-session professional development opportunities provide time for teacher instruction, classroom experimentation, and collaborative reflection and have been documented to provide greater teacher growth and student achievement (Darling-Hammond et al., 2017; Yoon et al., 2007).

In the same review of Eisenhower Professional Development Programs discussed earlier, the impact of program duration on teacher learning was evaluated. Programs that were sustained over several weeks or months with many hours of contact time showed positive influences on program coherence, content focus, and participants’ active engagement in learning. The majority of these long-term professional development programs offered extensive opportunities for teacher collaboration for strategizing implementation and reflecting on classroom success and issues to further support teacher growth (Birman et al., 2000; Garet et al., 2001).

**Modeling and engagement.**
Much research has suggested that teacher professional development is most successful when the intended teaching practice is modeled through instruction provided to teachers (Knapp, 2003). Putnam and Borko (2000) used a situative perspective to describe the effect of setting and context on teacher learning. Central to their analysis is the significance of fostering learning within the context of the teacher’s practice (Putnam & Borko, 2000). Therefore, it makes sense to deliver teacher professional development such that it models the target practice and provides opportunity to engage in the intended student experience. Professional development that models intended teacher and student interactions and provides examples of student work in the engineering context can help teacher participants to develop necessary pedagogical content knowledge in engineering (Knapp, 2003; Shulman, 1986).

**Professional development in engineering education.**
The integrative nature of NGSS presents a unique challenge for classroom teachers and teacher educators. One of the primary aims of NGSS is the incorporation of engineering practices with science content and practices in a cohesive course (NGSS Lead States, 2013). Very few science educators have either educational or practical experience with engineering and many have significant misconceptions or a complete lack of knowledge of engineering (Bybee, 2011;
Christian et al., 2018; Kimmel, Carpinelli, & Rockland, 2007). As a result, there is a need for professional development for science educators that will foster participants’ engineering literacy.

The literature suggests several key features of professional development for teachers of engineering. In addition to the considerations for productive professional development mentioned earlier, professional development in engineering education should also engage participants in authentic engineering practices and design challenges, expose teachers to different types of engineering, create opportunities for communication between educators and career engineers, and encourage teachers to relate engineering content to their subject area content while developing lessons (ASEE, 2014).

**Authentic engineering design experience.**

Because most science educators have little to no experience within the field of engineering, it is especially important that professional development activities in engineering provide opportunities for teachers to experience engineering design. Through these experiences, science teachers should develop an understanding of the design and optimization process while nurturing a sense of efficacy in their ability to teach these practices to their students, thereby increasing the likelihood of implementation in the classroom (National Academy of Engineering & NRC, 2014).

In one recent study, a summer professional development program for K-12 mathematics and science teachers provided content workshops, mentored summer experiences in research engineering, and support in developing mathematics and science aligned engineering design lessons (Ghalia, Carlson, Estrada, Huq, & Ramos, 2016). Teachers were organized in teams based on grade and subject taught, educational and professional background, and personal interests. Working with university engineering faculty, teachers carried out design research which culminated in the generation of a report and poster detailing their project. Based on survey responses about their learning, teachers developed a greater understanding of the practical applications of their content area knowledge, increased awareness of ongoing research in their content areas, renewed interest in continuing research in their field, and improved appreciation for the value of collaborative inquiry. In addition to their research work, teachers also collaborated to produce classroom activities integrating engineering in their course curricula. Ultimately, over three years of the program, teacher participants authored 36 lessons, of which 32 were successfully implemented in the classroom (Ghalia et al., 2016).

**Support from engineering professionals.**

Previous studies have shown a positive impact between teacher interaction with engineering professionals and faculty and teacher engineering knowledge growth during professional development opportunities (Hardré, Nanny, Refai, Ling, & Slater, 2010; Nugent, Kunz, Rilett, & Jones, 2010). These experiences with professionals may also provide teachers with exposure to a variety of engineering fields and real-world applications.

Participation in authentic engineering learning experiences has been shown to promote teacher understanding of engineering design and increase the likelihood of classroom implementation. One such program, the *Research Experiences for Teachers* summer resident program, provided teachers with the opportunity to work directly with engineering faculty to research a design question and develop associated lessons for use in their classrooms (Hardré et al., 2010). Seventeen mostly high school and middle school teachers participated in the six-week-long program and worked in one of three faculty-mentored lab settings on industrial, computer, or environmental engineering projects. Data were collected from online questionnaires, interviews, and observations.
throughout the year following the professional development opportunity. Teachers reported feeling highly engaged in their learning experiences and indicated their intention to make use of their acquired knowledge in their classroom teaching. It should be noted that some teacher participants found their experiences to be too contextual and did not see the relevance of their research experiences in relation to their teaching, supporting the importance of the situative context of learning. Many teachers reported a shift in their thinking about research from a procedural scientific method to a more problem-solving design-based approach. Researchers noted that teacher participants who had the most responsive and supportive engineering faculty mentors reported the greatest success in classroom integration of their experiences (Hardré et al., 2010).

An unrelated project provided additional support for the value of interaction between teachers and engineers in the field (Nugent et al., 2010). Through the course of a two-week summer experience, program facilitators introduced teachers to the work of engineers and supported the teachers in the design and use of content integrated engineering lessons. Teachers learned about practical examples of engineering design such as race car track safety, wastewater treatment, and traffic control using real data sets, simulations, and visits to research labs. Throughout the development of their lessons, teachers were supported by university engineering and education faculty. Survey data were collected immediately following the program and again seven months later. Teachers reported significant gains in engineering knowledge and demonstrated retention of that knowledge. Additionally, teachers reported gains in their students’ learning and motivation in science, mathematics, and engineering. This was supported by surveys that indicated a high percentage of students felt engaged in their teachers’ engineering lessons (75%) and learned about engineering from the lesson (86%) (Nugent et al., 2010).

**Connection to science content.**

There is significant value in the addition of engineering instruction in the science classroom to support science learning and understanding (Brophy et al., 2008; Moore et al., 2014). Research on reform has suggested that teachers were more likely to follow through on implementation when the effort was aligned with existing standards and expectations (Guskey, 2003; Penuel et al., 2007). Therefore, encouraging science teachers to incorporate engineering into their classrooms requires a definitive connection between the science content and the engineering knowledge and practice.

### 2.6 Conceptual Framework: Integrated Model of Engineering Pedagogical Growth

The preparation of science teachers to incorporate effectively the principles of engineering to supplement science content and curricula requires the development of teachers’ content knowledge and pedagogical content knowledge in the engineering design process (ASEE, 2014). In addition to the challenges associated with engineering instruction, there are deficiencies in the current practices of teaching science that will likely impede the successful implementation of NGSS. The conceptual model for this study is based upon research related to the interconnected nature of professional growth (Clarke & Hollingsworth, 2002), situated and social cognition in professional development (Borko, 2004), and knowledge integration as applied to science and engineering teaching and learning (Lee, Linn, Varma, & Liu, 2010). A conceptual framework for assessing teacher growth is based on self-efficacy theory and behavioral change (Bandura, 1977).
Interconnected model of professional growth.
The development of effective teaching practice is a complex process, occurring over time through teacher training and experience in various contexts. The interconnected model of professional growth attempts to characterize the influences contributing to the growth of a teacher’s pedagogical competencies. The model describes four domains of teacher change and their interrelationships within a defined teaching environment. The external domain describes the stimulus for professional change and the sources of instructional support that influence a teacher’s practice, such as state standards for instruction and assessment and professional development experiences. This external domain has a direct influence on teachers’ perceptions and awareness of the target growth area, as well as their behaviors in the classroom. The personal domain identifies a teacher’s attitudes towards the intended instructional innovation and his/her knowledge associated with the instructional practice. The domain of practice characterizes the pedagogical approaches of the teacher in the classroom, including the lessons he/she plans and carries out and his/her interactions with students and colleagues. The final domain is the domain of consequences, which describes the teacher’s conclusions regarding the progression of professional change, often based on the response of students to the pedagogical change. The ongoing interaction among the domains occurs through enaction and reflection. Teachers continuously use their experience and knowledge from one domain to influence their teaching practice through the other domains, while also using the observable change in each domain as reinforcement for their progression as a teacher (Clarke & Hollingsworth, 2002). The model supports the transformative impacts of any change in the external domain, while ongoing enaction and reflection through other domains contributes to long-term professional learning (Clarke & Peter, 1993). Additionally, the model acknowledges the influence of environmental factors on teacher growth, such as school expectations and resources, guiding standards and curriculum, and colleague interactions (Clarke & Hollingsworth, 2002).

Situated learning perspective and social cognition.
As this study considers the impacts of an in-person professional development experience, it is logical to consider the situated perspective for learning in analyzing the external domain and the environment influencing teacher growth (Clarke & Hollingsworth, 2002; Putnam & Borko, 2000). The situative theory of learning suggests that the process of knowledge acquisition is affected by the learning context, including the physical and social attributes of the setting (Putnam & Borko, 2000). With regard to teacher professional development, the situation of learning includes the program and content itself, the teacher participants in the learning experience, the facilitators coordinating the experience and disseminating information, and the physical setting and context of the experience. From this perspective, teacher learning is the product of individual teacher development and teacher involvement in a professional learning community (Borko, 2004). Consideration of the social aspects of a professional learning interaction, as well as the influence of the context of learning on the formation of teachers’ perceptions and understandings of
pedagogical change and classroom experimentation, is necessary in the development and analysis of teacher professional development (Desimone, 2009).

**Knowledge integration perspective.**
A unique aspect of the intended teacher growth associated with the inclusion of engineering in the science classroom is that it aims to supplement the teachers’ existing pedagogical repertoire, rather than replace existing pedagogical strategies. In light of this, it is necessary to also consider knowledge integration as one aspect of the personal domain, and as a model within the domain of practice (Chui & Linn, 2011; Clarke & Hollingsworth, 2002). The knowledge integration perspective describes the learning process through the reconciliation of existing knowledge with newly acquired content awareness (Chiu & Linn, 2011). The knowledge integration perspective of cognition has been evidenced in student learning. Since research has indicated that effective professional development models intended teaching practices, it is logical to use the knowledge integration framework to guide both classroom and professional development experiences (Knapp, 2003; Lee et al., 2010).

The knowledge integration perspective suggests that the acquisition of new knowledge is most effective when students are provided opportunities to use reason to discern the value of their new knowledge in relation to their preexisting notions regarding a phenomenon (Chiu & Linn, 2011). The knowledge integration framework identifies four steps in learning which promote the development of learners’ coherent conceptual understanding, which in the context of this study, involves the integration of engineering knowledge and skills in science instruction. Instruction should first elicit students’ pre-existing ideas about the target content with the goal of organizing, analyzing, and questioning their current understandings. Second, instruction adds new knowledge to students’ repertoire while providing continuing opportunities to discern between pre-existing science ideas and newly introduced engineering knowledge. This step requires exposure to learning in unique contexts, such as utilizing real-world engineering designs to learn about science concepts. Next, instruction should guide students in developing criteria to differentiate between engineering principles and unfounded notions. Instruction which provides opportunity for designing and testing prototypes can facilitate this step in the process. Finally, students should be encouraged to use reasoning and optimization skills to synthesize science content, resolve design discrepancies and conflicting data, and developing scientifically legitimate explanations while continuing to question the validity of their engineering knowledge (Lee et al., 2010).

In the context of this study, teacher participants were challenged to augment their existing science pedagogical content knowledge with new knowledge of engineering design and pedagogy. The professional development experience not only introduced teachers to the disciplinary principles associated with engineering but also challenged teachers to integrate that knowledge with their science course content. In doing this, teachers developed a thorough understanding of the engineering process and identified relevant applications of design in their science courses. The conceptual framework of this study, which consists of multiple interrelated aspects of engineering pedagogical growth, is represented in Figure 2.
Self-efficacy theory.
One of the primary goals of most professional development programs is to alter teachers’ behavior in the classroom. Behavioral change can be influenced through growth in teachers’ perceptions of their own efficacy related to the targeted practice. Self-efficacy is developed through four sources: performance accomplishments, vicarious experiences, verbal persuasion, and physiological states (Bandura, 1977). A well-designed professional development program can contribute to the growth of teachers’ self-efficacy by providing opportunities for teachers to engage successfully in instructional tasks with a positive emotional outcome, witness examples of the successful implementation of the target practice by others, and experience verbal encouragement and support from peers and instructors. Because self-efficacy is a construct of one’s perceptions of themselves, growth in this area can be measured through a survey instrument completed by teachers before and after participating in professional development. Self-efficacy theory supports that growth in self-efficacy can be expected to lead to behavioral change (Bandura, 1977).
Chapter 3

Methodology

3.1 Introduction

Establishing high quality effective and accessible professional development in engineering for science teachers is essential for the successful adoption of NGSS and the advancement of STEM education in the U.S. This study measured three aspects of secondary science teachers’ beliefs regarding engineering education prior to and following their participation in an immersive professional development experience in engineering education based on the research outlined earlier. A mixed methodology utilizing both survey instruments and teacher interviews was used to inform the following research questions:

1. How does professional development in engineering education affect secondary school science teachers’ beliefs about the value of using engineering design to support science learning?
2. How does professional development in engineering education affect secondary school science teachers’ self-efficacy regarding teaching engineering in their science courses and providing advisement for engineering careers?
3. What obstacles do science teachers identify during the implementation of engineering practices in their science classes?

3.2 Research Design

A convergent parallel mixed methods design (Creswell, 2013), in which qualitative and quantitative data contributed simultaneously to the interpretation of results, was employed in this research. The use of multiple methods of data collection strengthened this study by providing validated findings to inform a rich contextual understanding of teacher attitudes and approaches to teaching engineering (Creswell, Plano Clark, Gutmann, & Hanson, 2003). A predominantly phenomenological approach was used to interpret the influence of the engineering professional development experience on science teachers and their implementation of engineering in their science courses. Elements of grounded theory were employed during the analysis of data, as the existing research does not provide a complete framework for interpreting these findings (Creswell, 2013).

A mixed methods design approach was employed to assess multiple aspects of science teacher beliefs and self-efficacy in teaching engineering design. A convergent parallel triangulation design informed the three research questions. This approach resulted in a more complete and thorough depiction of science teacher attitudes towards engineering than a solely quantitative or qualitative analysis could provide. Triangulation between methodologies increased confidence in the study findings as well as illuminated elements of teacher attitudes that did not fit the planned theoretical model (Jick, 1979).
The convergent parallel triangulation strategy provided cross-validation of qualitative and quantitative results. In addition, limitations in the descriptive value of the survey instruments were addressed with interview questions that allowed for a deeper investigation of individuals’ knowledge, attitudes, and self-efficacy related to teaching engineering. Surveys were administered and interviews conducted prior to the start of the professional development experience and again at the conclusion of the course. The analyses of each dataset occurred independently and were later combined to provide corroboration and a thoroughly detailed analysis of each of the research questions (Creswell et al., 2003).

3.3 Context

As many states continue the process of updating their science education standards to align with NGSS, there is a growing need for quality professional development to support teachers’ efforts to implement the new standards. Continued research regarding the preparation of science teachers for integrating engineering into their courses is particularly relevant in New York State, where this study was conducted. In 2016, the New York State Education Department (NYSED) officially adopted a minimally modified version of the NGSS to guide science instruction in grades K-12 (NYSED, 2016a, 2016b). As in NGSS, the New York State P-12 Science Learning Standards identified specific performance objectives associated with both science and engineering practices (NGSS Lead States, 2013; NYSED, 2016b). This is a significant revision from the previous version of science education standards as there was no mention of engineering in the former science core curriculum (NYSED, 1996).

New York State secondary science teachers are certified in one or more of the following areas: biology, chemistry, Earth science, or physics. In New York State, the typical teacher certification pathway includes completion of a teacher education program with an institutional recommendation from a higher education facility and acceptable scores on both a teacher certification exam and a content-specific exam (NYSED Office of Teaching Initiatives, 2015). While programs can vary, the typical undergraduate science teacher preparation coursework at a school in the State University of New York (SUNY) system includes completion of approximately 36 credits within the intended certification area, as well as completion of additional credits in the other science domains and mathematics. Approximately 24 credits in pedagogy, including supervised student teaching experience, are also required. All teachers that pursue this pathway to certification must complete a master’s degree within five years of completing their initial certification. A typical graduate program in a SUNY school requires an undergraduate degree in a science course of study. Additionally, graduate students will complete 15 credits in content-specific courses, 20 credits in pedagogy and methods courses, and 9 credits of supervised student teaching (Stony Brook University Institute for STEM Education, 2019b). Alternate pathways towards certification are possible for individuals transitioning from other careers into teaching or teachers with certifications in another state. None of these pathways, traditional or non-traditional, requires science teacher candidates to complete any engineering or technology credits for certification (NYSED Office of Teaching Initiatives, 2015).

All study participants were employed as teachers in one of a number of suburban school districts located throughout Long Island, New York. In New York, to qualify for a high school diploma, general education students in public schools are required to complete three credits of high school science. One course of instruction must be in the life sciences, one in the physical sciences (Earth science, physics, or chemistry), and the third could be any designated science course.
Curricula for these courses are generally defined by NYSED and students must pass (minimum score of 65) at least one standardized state exam associated with one of these courses. There is not a specific state requirement for high school coursework in technology or engineering. Students are required to complete an additional 3.5 elective credits but there has traditionally been variation in the availability of offerings among schools (Kelly & Sheppard, 2009; NYSED, 2017; Padwa et al., 2018).

Study participants voluntarily enrolled in one or both of two multi-session professional development workshops for teachers offered on a local college campus. The content of the courses varied as one workshop focused on applications of electrical engineering and the second was focused on biological engineering. The courses were developed in collaboration between university science education and engineering faculty and based on recent literature regarding high quality teacher professional development described earlier and summarized in Table 2. As such, each course was designed to focus specifically on the engineering design principles that were emphasized throughout NGSS (NGSS Lead States, 2013). Class sessions were facilitated by both science education and engineering faculty. Numerous opportunities throughout the course allowed teachers to collaborate with each other and science and engineering researchers to draw connections between the engineering principles and the relevant science course content. Previous studies have shown that this model for engineering professional development increases program efficacy (Hardré et al., 2010; Nugent et al., 2010).

Table 2. *Workshop Alignment to High Quality Professional Development* (adapted from Birman et al., 2000; Bybee, 2011; Darling-Hammond et al., 2017; Guskey, 2003; Kimmel et al., 2007; Supovitz & Turner, 2000)

<table>
<thead>
<tr>
<th>Effective Teacher Professional Development</th>
<th>Electrical Engineering Workshop</th>
<th>Bioengineering Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content focus</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Coherence</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Participant collaboration</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Modeling &amp; engagement</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effective Teacher Professional Development in Engineering Education</th>
<th>Electrical Engineering Workshop</th>
<th>Bioengineering Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authentic engineering design experience</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Support from engineering professionals</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Connection to science content</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

As the literature has suggested, professional development has been most effective when it modeled the intended teaching practice (Knapp, 2003; Shulman, 1986). As such, the course was designed to engage teachers in the engineering design process through a number of content specific activities facilitated by engineering faculty. Using the integrated knowledge framework perspective, the courses were designed to foster teachers’ knowledge of engineering by calling upon their pre-existing knowledge of science to develop their ability to integrate science and engineering effectively in their own classrooms.
3.4 Participants

Data were collected from 21 participants in the two workshops. A total of 14 teachers responded to both the pre- and post-workshop surveys during the electrical engineering workshop and 7 teacher participants replied to both surveys during the biological engineering sessions. Six participants attended both the electrical engineering and bioengineering workshop series; only their survey responses for the first workshop in electrical engineering were included for analysis. Additionally, a control sample of 28 teachers completed the same survey. The teachers’ course assignments and years of experience are shown in Table 3. All respondents were either middle or high school STEM teachers who were actively teaching in a variety of suburban school districts located throughout Long Island, New York.

Table 3. Workshop Participant Teaching Experience

<table>
<thead>
<tr>
<th>Course(s) taught at time of study (some teachers identified more than one subject area)</th>
<th>Electrical Engineering Workshop Participants ( (n=14) )</th>
<th>Bioengineering Workshop Participants ( (n=7) )</th>
<th>Control Sample ( (n=28) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>3</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Chemistry</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Earth Science</td>
<td>3</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Physics</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Other Science</td>
<td>5</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Mathematics</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Computer Science</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Technology</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engineering</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years of Teaching Experience</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 years</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6-10 years</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>11-15 years</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>16 or more years</td>
<td>7</td>
<td>5</td>
<td>16</td>
</tr>
</tbody>
</table>

The workshops were offered as a professional development opportunity for teachers participating in the New York State Master Teacher Program (NYSMTP). In New York, Master Teachers were selected for a four-year appointment following an application and interview process. Acceptance criteria included mastery of STEM content knowledge, pedagogical knowledge, and knowledge of and involvement with their students and school community. Master Teachers were required to complete at least 50 hours of NYSMTP-organized professional development each year through the program while maintaining their full-time STEM classroom teaching positions. Both of the workshops reviewed in this study satisfied hours towards this requirement. Master Teachers also had to maintain an Annual Professional Performance Review rating (determined by the school district in which they were employed) of “effective” or “highly
effective” for the duration of their commitment to the Master Teacher program. NYSMTP participants were compensated with a $15,000 annual stipend for each of their four years in the program (State University of New York, 2019).

Teachers were solicited for participation in voluntary interviews prior to the start of each workshop series. Requests for interviews were sent to teachers based on their teaching content area, school district, and involvement in the NYSMTP. Four teachers consented to participate in interviews both before and after the electrical engineering workshop series. Two teachers from the biological engineering workshops participated in both a pre- and post-workshop interview. The teachers were all employed within the same region of New York State but each worked in a different school district. Two teachers worked in high-needs schools with the majority of students considered economically disadvantaged. One of these teachers worked in a district with large population of Hispanic and Latino students with nearly one-third of all students requiring support as English Language Learners (ELL). The rest of the districts were relatively homogenous, with significantly lower ELL and economically disadvantaged populations. All of the interview participants were experienced teachers; three of the teachers had 11-15 years of classroom teaching experience and three had been teaching for longer than 15 years. A brief profile of each interviewed teacher (with pseudonym), his/her teaching experience, and school district demographics are summarized in Table 4.
Table 4. Teacher Interview Participants (NYSED, 2018)

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Primary Teaching Content Area &amp; Level</th>
<th>Years of Teaching Experience</th>
<th>School District Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>District Enrollment (2017-2018)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>New York State</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2,622,879</td>
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<tr>
<td>Pedro</td>
<td>Earth Science</td>
<td>16+</td>
<td>6,131</td>
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<tr>
<td></td>
<td>MS</td>
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<tr>
<td>Joseph</td>
<td>Physics</td>
<td>11-15</td>
<td>4,933</td>
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<tr>
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<td>HS</td>
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<tr>
<td>Jack</td>
<td>Physics</td>
<td>11-15</td>
<td>6,144</td>
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<td>HS</td>
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<tr>
<td>Lydia</td>
<td>Biology</td>
<td>11-15</td>
<td>8,657</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td></td>
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<tr>
<td>Sophie</td>
<td>Biology</td>
<td>16+</td>
<td>18,903</td>
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<tr>
<td></td>
<td>HS</td>
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<tr>
<td>Richard</td>
<td>Biology</td>
<td>16+</td>
<td>3,373</td>
</tr>
<tr>
<td></td>
<td>HS</td>
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</table>
3.5 Preliminary Data Informing Workshop Design

In order to maximize the effectiveness of the workshop structure, experienced secondary science teachers were given a pre-treatment survey modified from two existing validated, reliable questionnaires – the *Teaching Engineering Self-Efficacy Scale* (Yoon, Evans, & Strobel, 2014) and the *Familiarity with Design, Engineering & Technology (DET) Survey* (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006). Relevant items were selected with the assumption that most respondents had limited experience in teaching engineering design principles in a science classroom. These items provided the research team with baseline data on science teacher attitudes towards and preparedness for implementing NGSS.

In a pilot study conducted before the main study (Christian et al., 2018), 22 secondary science teachers, 14 women and 8 men, responded to the survey with a range of teaching experience from 7-25 years and a mean of 15 years. Their primary subjects taught included biology ($n=7$), chemistry ($n=8$), Earth science ($n=3$), and physics ($n=4$). Items and response percentages are presented in Table 5. The science teachers indicated a strong interest in becoming more proficient in teaching engineering design, yet less confidence in their ability to do so effectively. Notably, they overwhelmingly agreed that they did not receive adequate pre-service training in teaching engineering design; this indicated the need for in-service professional development opportunities to improve teacher proficiency in helping students meet NGSS objectives. Teachers shared a commitment to communicate the importance of engineering through integrated instruction, and overall appreciation for the value of NGSS in improving science learning in an increasingly technological society. The teachers were largely neutral regarding whether their school districts supported efforts to incorporate engineering in science, suggesting that school leaders and administrators also require professional development regarding the importance of the standards in improving STEM education for all students (Christian et al., 2018).
Table 5. Science Teacher Responses to Engineering Teaching Efficacy Survey

<table>
<thead>
<tr>
<th>Importance of engineering and design</th>
<th>Response Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
<td>SA</td>
</tr>
<tr>
<td>1. I would like to be able to teach my students to understand the use and impact of engineering and design.</td>
<td>48</td>
</tr>
<tr>
<td>2. I would like to be able to teach my students to understand the science underlying engineering and design.</td>
<td>48</td>
</tr>
<tr>
<td>3. In a science curriculum, it is important to include planning of a project.</td>
<td>52</td>
</tr>
<tr>
<td>4. I am interested in learning more about engineering and design through in-service workshops.</td>
<td>30</td>
</tr>
<tr>
<td>5. I am interested in learning more about engineering and design through college courses.</td>
<td>27</td>
</tr>
<tr>
<td>6. I am interested in learning more about engineering and design through peer training.</td>
<td>30</td>
</tr>
<tr>
<td>7. I would like to be able to teach my students to understand the design process.</td>
<td>52</td>
</tr>
<tr>
<td>8. I would like to be able to teach students to understand the types of problems to which engineering and design can be applied.</td>
<td>57</td>
</tr>
<tr>
<td>9. Engineering and design have positive consequences for society.</td>
<td>83</td>
</tr>
<tr>
<td>10. I support the integration of engineering and design in the K-12 curriculum.</td>
<td>57</td>
</tr>
<tr>
<td>11. In a science curriculum, it is important to include the use of engineering in developing new technologies.</td>
<td>57</td>
</tr>
<tr>
<td>Familiarity and self-efficacy with engineering content knowledge</td>
<td></td>
</tr>
<tr>
<td>12. I feel confident about integrating more engineering and design in my curriculum.</td>
<td>17</td>
</tr>
<tr>
<td>13. I can describe the process of engineering design.</td>
<td>17</td>
</tr>
<tr>
<td>14. I can explain the ways that engineering is used in the world.</td>
<td>22</td>
</tr>
<tr>
<td>15. I can discuss how engineering is connected to my daily life.</td>
<td>26</td>
</tr>
<tr>
<td>16. My pre-service training was effective in supporting my ability to teach engineering and design at the beginning of my career.</td>
<td>9</td>
</tr>
<tr>
<td>17. I use engineering and design activities in the classroom.</td>
<td>4</td>
</tr>
<tr>
<td>18. I am familiar with the New York State P-12 Science Learning Standards.</td>
<td>39</td>
</tr>
<tr>
<td>19. My school supports my use of engineering and design activities.</td>
<td>13</td>
</tr>
</tbody>
</table>

Response codes: SA = strongly agree, A = agree, N = neutral, D = disagree, SD = strongly disagree

### 3.6 Workshop Structure

In response to preliminary data, the goal of the workshops in this study was to challenge teacher participants to augment their existing science pedagogical content knowledge with new knowledge of engineering design and pedagogy. The professional development experience not only introduced teachers to the disciplinary principles associated with engineering but also supported them in integrating that knowledge with their science course content. In doing so, teachers developed an understanding of the engineering process and identified relevant applications of design in their science curricula.
**Contextual factors.**
Teacher participants were employed in a number of school districts located throughout Long Island, New York. In New York State, science teachers are certified in at least one specific discipline: biology, chemistry, Earth science, physics, or general science. Long Island science teachers are unique in that many are certified in at least two science disciplines; for example, the majority of chemistry teachers in the region have a primary certification in biology (Padwa et al., 2019). Middle school science teachers were often required to teach all of the science disciplines in a spiral curriculum consistent with NGSS, and all science teachers needed to emphasize crosscutting concepts that link disciplinary domains (NGSS Lead States, 2013). New York State science teachers must demonstrate disciplinary competence in all four basic sciences to earn a 7-12 teaching license (NYSED, 2018). Consequently, a professional development course that incorporates engineering practices in more than one science discipline was both desirable and necessary to meet the needs of Long Island teachers and their students.

**Refining and building upon prior professional development models.**
Although there have been many published works on general principles of effective teacher professional development for meeting NGSS, as well as assessing lesson alignment and developing performance expectations, few researchers have provided empirical support for specific teacher training regarding integration of science and engineering for a yearlong course at the secondary level (Banilower, Gess-Newsome, & Tippins, 2014; Duschl & Bybee, 2014; Purzer et al., 2014; Krajcik, Codere, Dahsah, Bayer, & Mun, 2017; NGSS Lead States, 2018; Wilson, 2013). This is particularly important for science teachers in New York State since all high school and many middle school students take high stakes cumulative exams, known as Regents exams, to measure whether they meet state standards. The novel workshop design employed in this study provided secondary science teachers with affordable, rigorous engineering activities, while equipping teachers with the tools to develop NGSS- and state-aligned curricula in several science domains. Some of the activities had been previously piloted and evaluated with middle and high school students in other outreach programs (Bugallo & Kelly, 2014, 2015, 2017; Bugallo, Kelly, & Ha, 2015). Throughout the sessions, teachers had numerous opportunities to collaborate with peers and university faculty to draw connections between engineering principles and relevant science content. Previous research has shown that this model for professional development increases program efficacy (Hardré et al., 2010).

**Session activities.**
This course was developed collaboratively between university science education and engineering faculty based on recent literature regarding high quality teacher professional development. As such, the course focused specifically on the engineering design principles that were emphasized throughout the NGSS and ASEE standards (ASEE, 2014; NGSS Lead States, 2013). Class sessions were co-taught by science education and engineering faculty. To maximize broader impacts, workshops were presented in two modules: 1) electrical engineering co-taught with physics education faculty; and 2) biomedical engineering co-taught with biology education faculty. Each module addressed disciplinary core ideas, crosscutting concepts, and science and engineering practices through theory-based readings and discussions, hands-on tasks, and collaborative curriculum design. Some of the relevant NGSS for each workshop are summarized in Table 6. Consistent with NGSS, the workshop activities were framed for identifying problems and defining related limitations and criteria for technological advancements. Teachers generated and evaluated
a variety of solutions to identified problems. Finally, they optimized solutions through analysis of the value and costs associated with their designs (NGSS Lead States, 2013).

Table 6. *Workshop Activities with Sample NGSS Alignment* (NGSS Lead States, 2013)

<table>
<thead>
<tr>
<th>Electrical Engineering: Building a Nightlight</th>
<th>NGSS Standard: MS-PS2-3. Ask questions about data to determine factors that affect the strength of electrical and magnetic forces. NGSS Standard:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI:</td>
<td>PS2.B: Types of interactions</td>
</tr>
<tr>
<td>CCC:</td>
<td>Cause and effect</td>
</tr>
<tr>
<td>SEP:</td>
<td>Asking questions and defining problems</td>
</tr>
<tr>
<td>NGSS Standard: MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.</td>
<td></td>
</tr>
<tr>
<td>DCI:</td>
<td>ETS1.A: Defining and delimiting engineering problems</td>
</tr>
<tr>
<td>CCC:</td>
<td>Influence of science, engineering, and technology on society and the natural world</td>
</tr>
<tr>
<td>SEP:</td>
<td>Asking questions and defining problems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical Engineering: Home Security System</th>
<th>NGSS Standard: HS-PS3-1. Create a computation model to calculate the change in the energy of one component in a system when the change in the energy of the other component(s) and energy flows in and out of the system are known.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCC:</td>
<td>Systems and system models Scientific knowledge assumes an order and consistency in natural systems</td>
</tr>
<tr>
<td>SEP:</td>
<td>Using mathematics and computational thinking</td>
</tr>
<tr>
<td>NGSS Standard: HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.</td>
<td></td>
</tr>
<tr>
<td>DCI:</td>
<td>ETS1.B: Developing possible solutions</td>
</tr>
<tr>
<td>CCC:</td>
<td>Influence of science, engineering, and technology on society and the natural world</td>
</tr>
<tr>
<td>SEP:</td>
<td>Constructing explanations and designing solutions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bioengineering: Microbial Fuel Cell</th>
<th>NGSS Standard: HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI:</td>
<td>LS1.C: Organization for matter and energy flow in organisms</td>
</tr>
<tr>
<td>CCC:</td>
<td>Energy and matter</td>
</tr>
</tbody>
</table>
**Electrical Engineering Workshop.**

The first workshop series focused on the integration of electrical engineering in a variety of science contexts. This workshop met for three sessions of two hours each. Meetings were held in the evenings in an electrical engineering lab classroom at the university designed to host middle and high school classes visiting campus on field trips. Each laboratory station could accommodate two students with a shared computer, soldering station, and power source, along with other basic tools. This arrangement facilitated the collaboration of teachers in partnerships as they worked on their engineering projects. The electrical engineering workshops were taught collaboratively by three instructors affiliated with the university hosting the workshops. The primary instructor, Instructor 1, was a university faculty member who taught in the Physics Department and Science Education Program and had previous experience as a high school educator. Instructor 2 was a doctoral student in the Electrical and Computer Engineering Departments. Instructor 3 was also a professor in Electrical and Computer Engineering. Each instructor contributed to the design of the course, the selection and format of the activities, and the presentation of material in each session.

The primary objectives of the electrical engineering workshop series were to: 1) review the NGSS format and relevant standards, 2) introduce the engineering design process, 3) engage teachers in two electrical engineering projects (designing a nightlight and a home security system), 4) discuss classroom implementation and assessment, and 5) differentiate engineering disciplines and careers. The first session began with instructor and participant introductions. Instructor 1 provided a brief overview of the workshop series and an overview of associated engineering education outreach programs to support K-12 students and school guidance counselors. She continued with data to support the value of engineering education in preparation for post-secondary education and the workplace. A brief overview of NGSS, with emphasis on the science and engineering practices and crosscutting concepts related to the planned workshop activities, established the relevance of the tasks in the secondary classroom. Instructor 2 then presented some foundational knowledge about the first planned activity, *Building a Nightlight*. To accommodate the varying backgrounds of teacher participants, it was necessary to establish at least a minimal understanding of the operational components of the nightlight system, such as a resistor, breadboard, integrated circuit, and potentiometer. Once it was established that teachers could identify the components of the system and interpret a circuit diagram, they were able to work independently, following the given instructions, to complete the construction phase of the *Building a Nightlight* activity. Both Instructor 1 and Instructor 2 circulated through the classroom providing support to teachers as they worked for approximately 45 minutes.

The *Building a Nightlight* project (for a detailed description, see Krayem, Kelly, Westerfeld, & Bugallo, under review) involved using a breadboard, RGB LED, several resistors (1-130Ω, 2-
56Ω), wiring, and a USB cable to construct a working circuit to light the LED bulb. Using three potentiometers to modify the LED color, teachers completed experiment phase 1 of the activity to optimize the output of the LED light. In experiment phase 2, participants installed a pre-programmed microcontroller to shift colors automatically. Additionally, participants were able to customize their light with a clear acrylic panel painted with transparent matte paint. The kit components were acquired for a total cost of $6 per participant. Teachers were supplied with the materials to complete their own nightlight to take back to their classrooms after the workshop session. To conclude the first session, Instructor 3 presented a lecture about the science of light from both a physical sciences and biological sciences perspective.

Sessions two and three of the electrical engineering workshop were centered on a Build Your Own Home Security System activity (for a detailed description, see Krayem et al., 2018). In this project, participants assembled a circuit with an alarm and timer to track disruption in a light beam generated by a laser. Each assembly required a printed circuit board, a USB receptacle, a 14 pin socket, a phototransistor, several capacitors (3-0.01uF, 1-2.2uF), several resistors (1-4.7kΩ, 1-100Ω, 1-1MΩ, 1-18kΩ, 1-220Ω), and a buzzer. The complete kit of components was assembled for $6 per user. Additional supplies for soldering were necessary for this project. Opportunities for refinement were presented as participants were able to manipulate the period and frequency of the alarm buzzer for optimized functioning. Again, teachers were able to take their completed alarms to their classrooms at the conclusion of the final workshop session.

The second session followed a similar format to the first with Instructor 1 reiterating the relevant NGSS standards and discussing the implementation of these activities in both middle and high school science courses. Instructor 2 introduced the components of the Build Your Own Home Security System activity and emphasized the safety protocol associated with soldering. Participants followed the instructions for assembling the alarm circuit. Both Instructor 1 and Instructor 2 provided support as needed while teachers worked independently on their projects. After 45 minutes, the group reconvened and Instructor 2 explained the mechanism of action of the alarm system, including calculations for the period and frequency of the alarm that could be modified with varying capacitors and resistors in the circuit. By the end of session two most participants had completed the assembly of their alarm system.

Session three began with Instructor 1 reviewing the previous session’s activity. Instructor 2 then lectured about the microchips that were subsequently installed in each alarm system that evening. By the end of the first hour of the session most teachers had finished assembling and optimizing their alarm systems and the instructors began a conversation with the group about the implementation of both the nightlight and home alarm system projects in the secondary science classroom. Instructor 1 again reiterated the relevance of the projects with regard to NGSS and introduced an assessment rubric template. She directed teachers to work in pairs to discuss how they might use the rubric or make modifications to the rubric when doing these engineering activities in their classroom with their students. After working in pairs, the larger group reconvened to continue the discussion on assessing student work in engineering. Finally, all three instructors shared information about different fields in engineering and the university expectations for applicants to engineering programs. This part of the presentation included the distribution of classroom-ready laminated engineering posters. Each teacher received a set of seven fliers profiling a different engineering field at the university, including chemical and molecular, civil, computer, computer science, electrical, mechanical, and technology and society. Each poster included a description of career options, pre-college course work, and a link to the department’s website (Stony Brook University Institute for STEM Education, 2019a).
Biological Engineering Workshop.

The second workshop series was designed to explore the applications of technology in the biological sciences. This workshop took place during two evening sessions of two hours each. Participants met in a university biology laboratory classroom with workstations arranged to encourage collaboration between teachers sharing materials and resources. Two instructors participated in the design and facilitation of this workshop series. The primary instructor, Instructor 4, served as director of the University teaching lab which hosted middle and high school class trips to engage in high quality lab experiences on campus. Instructor 5 was a master’s student in the University’s teacher preparation program with experience working with middle and high school students in the teaching lab.

The primary objectives of the bioengineering workshop series were to: 1) review the relevant NGSS, 2) review the engineering process, 3) engage teachers in the design and optimization of a fuel cell, and 4) discuss classroom implementation and assessment. The first session began with a presentation by Instructor 4 regarding the historical context for engineering, with emphasis on engineering applications for power generation. He introduced participants to the first project, design and construction of a potato battery. Individuals were challenged to engineer the most productive battery by manipulating a number of variables such as type of potato, temperature of potato, alternative conductors (lemons and tangerines), using multiple potatoes, and distance between electrodes. Teachers worked in pairs or groups of three to engineering the most productive bio-battery given the available resources. Teachers were given multimeters to measure their battery’s output. About halfway through the session the group reconvened and Instructor 4 proposed microbes as an alternative biological energy source. He introduced the next project, constructing and optimizing a microbial fuel cell. In emphasizing the optimization phase of the project Instructor 4 facilitated a conversation about the possible variables that could be introduced to the system, such as temperature, pH, added sugar source, soil type, and water type. Teachers then worked in pairs to identify a specific variable to test. Each member of the pair set up a fuel cell with some variation of their environmental variable.

The fuel cell project utilized kits purchased from www.magicalmicrobes.com for $39.99 per set up. Each kit contained a plastic vessel and lid, graphite anode, graphite cathode, hacker board, capacitor, LED bulb, and digital clock. Soil, water, and any additional tested environmental variable were supplied separately. Once assembled and left to mature for a week or two, a working fuel cell should have generated enough energy to light the LED bulb or power the clock. In this case, teachers were also able to use the multimeters from the first session to measure the output of the fuel cells. At the conclusion of both sessions, teachers were invited to keep all of the materials associated with both the potato battery and the microbial fuel cell for use in their own classrooms.

The second session met a week later. The instructors had all of the fuel cells assembled in the first session displayed in the middle of the room. After one week, none of the fuel cells were functioning. This prompted a group conversation to identify the failure and troubleshoot the system for the future. Instructor 4 then discussed the applications of this technology on a larger scale to address global energy challenges. Instructor 5 presented on the value of engineering in science and reviewed the engineering design process. Teachers were given time to reflect on the microbial fuel cell activity in small groups. They were asked to identify specific NGSS crosscutting concepts, disciplinary core ideas, and science and engineering practices that could be associated with the activity in the classroom. Teachers then shared their ideas in a larger group discussion and Instructor 5 made specific references to the NGSS engineering standards by distributing a copy of
the standards to all teachers. Finally, both instructors introduced careers of fields of study in science and engineering that were directly related to the fuel cell activity.

3.7 Quantitative Methods

Measures and instruments.
The Engineering Professional Development Survey (Appendix A) was used to measure various aspects of participants’ familiarity with engineering and self-efficacy in teaching engineering prior to participation in each workshop series and again at the conclusion of each series. The survey was administered once to a control group of demographically similar science teachers working in school districts within the same geographic area as the workshop participants. The survey administered to participants prior to the workshops as well as the control group survey were also used to collect background information about teacher education, certification, teaching experience, and prior professional development and teaching experiences in engineering. The majority of surveys were administered electronically through Qualtrics. Some workshop participants opted to complete paper versions of the same survey. The 20 question Likert inventory used in both the pre- and post-professional development surveys had a high internal consistency (Cronbach’s $\alpha = 0.945$).

The majority of the survey items (items 1-15) were modified from the Teaching Engineering Self-Efficacy Survey (TESS). This six-point Likert scale survey developed by Yoon et al. (2014) was based on the literature in the areas of self-efficacy and engineering education professional development. The original TESS consisted of 41 items intended to measure six factors associated with teacher self-efficacy in teaching engineering: engineering content knowledge self-efficacy, motivational self-efficacy, instructional self-efficacy, engagement self-efficacy, disciplinary self-efficacy, and outcome expectancy. The TESS items were reviewed by a panel of professors, K-12 science educators, and graduate students in engineering and education for content validity. The initial instrument was field tested with 153 teachers with overall reliability of the instrument of Cronbach’s $\alpha = 0.98$ ($N=153$). A subsequent exploratory factor analysis ($N=281$) demonstrated good internal consistency with values ranging from $\alpha = 0.84$ to $\alpha = 0.98$ for each factor (Yoon et al., 2014). Items used in the Engineering Professional Development Survey were selected from the TESS to specifically assess self-efficacy in four areas: content knowledge, motivation, instruction, and engagement based on the objectives of the professional development experiences and the recommendations of the ASEE for engineering professional development (ASEE, 2014).

Items 16-20 of the Engineering Professional Development Surveys were included to assess teachers’ awareness of engineering careers and familiarity with the Next Generation Science Standards. Among the primary objectives of the NGSS is to prepare students for future STEM careers (NRC, 2012). Student awareness of potential educational and career opportunities is essential to this mission (NRC, 2012). Establishing teacher familiarity with the NGSS was necessary to inform the design of the workshop. The same six-point Likert scale introduced in the TESS was appropriate for assessing these items as well (Yoon et al., 2014).

Data analysis.
Quantitative data were analyzed through a theory-driven, longitudinal assessment that simultaneously informs the qualitative phase. Pre- and post-experience within-group and between-group differences were analyzed with inferential statistics. Independent-samples and paired-samples $t$-tests provided measures of change attributable to the professional development
experience while controlling for other variables associated with the program participants. In this case, the comparison of means identified any significant differences between the responses of the control group and the post-experience survey responses of teacher participants, while also comparing pre- and post-experience responses of the participants. Missing data were deleted listwise since there were so few incomplete responses. Descriptive and inferential statistics were generated to inform interview protocol formatively for the qualitative research component.

3.8 Qualitative Methods

Using a phenomenological perspective, this research addressed two general themes: 1) change in teacher attitudes towards teaching engineering in their science courses, and 2) anticipated or experienced obstacles associated with integrating engineering content with science content. The analysis of interview responses for these two distinct themes required two different coding techniques.

Semi-structured interview protocol.
A semi-structured interview protocol guided the pre- and post-experience interviews with informed and consenting teacher participants. Interviews took place with individual participants at a mutually agreeable time and location with minimal distractions. Audio recordings of the interviews were obtained and stored in a secure location with no identifying information associated with the participants. Interview content was transcribed and coded (Creswell, 2013). Six teachers were selected and agreed to participate in two interviews each. The first interviews took place within the two weeks preceding the first workshop session. The second interviews occurred several weeks after the final workshop session but within three months of the pre-workshop interview.

Semi-structured interview questions are included in the Pre-Professional Development Semi-Structured Interview Protocol (Appendix B) and the Post-Professional Development Semi-Structured Interview Protocol (Appendix C). The pre-experience interviews aimed to assess teacher participants’ awareness of the state science learning standards and familiarity with engineering design. Questions also targeted teacher attitudes towards the value of engineering in science education and their confidence in being able to incorporate engineering prior to this professional development experience. The follow-up interview assessed the same constructs: teacher self-efficacy and perceived value of engineering in their science course. Additionally, post-experience questions measured teacher knowledge of engineering and competence in teaching engineering. Teachers also characterized their continued concerns about the implementation of engineering in their science courses following the workshops.

Coding techniques.
With concurrent triangulation mixed method design in mind, it was logical to apply a magnitude coding technique in analyzing responses related to teacher attitudes towards engineering in science and engineering teaching self-efficacy to cross-validate responses on the related survey items (Creswell et al., 2003; Saldaña, 2009). Preliminary structural codes were anticipated to be: perceived value of engineering, teaching engineering design self-efficacy, and engineering-science integration self-efficacy. Magnitude coding further differentiated responses along a scale: minimal value, some value, high value or low self-efficacy, developing self-efficacy, high self-efficacy (Creswell et al., 2003). Coded interview responses related to self-efficacy were compared to
individuals’ responses on the Teaching Engineering Self-Efficacy instrument for added validity (Saldaña, 2009; Yoon et al., 2014).

To inform the third research question concerning challenges in integrating engineering instruction, a strictly structural coding technique was employed. A structural coding technique allowed for indexing responses into categories related to a number of possible factors inhibiting a teacher’s successful integration of engineering into their science course (Saldaña, 2009). Based on the literature regarding education reform implementation, it was anticipated that several themes would emerge as obstacles: personnel (administrators, colleagues, students), resources (equipment, curriculum), and course expectations (class time, standardized testing) (Anderson, 1996; Darling-Hammond et al., 2017; Fullan & Miles, 1992; Kimmel et al., 2007).

Reliability.
Verification techniques were applied throughout the qualitative phase of data collection and analysis to ensure rigor. Ad-hoc reflection and re-evaluation may protect the validity and reliability of qualitative data primarily through researcher responsiveness. Building verification mechanisms into the data collection and analysis phase of research, rather than assessing these aspects at the conclusion of the study, may prevent the accumulation of bias and misrepresentation of findings. In each workshop series, pre-workshop interview responses were evaluated to guide probing questions for each participant during the post-workshop interviews. Themes that emerged in teachers’ responses before the workshop were explored in more depth during the subsequent interview to provide rigor through verification (Morse, Barrett, Mayan, Olson, & Spers, 2002). Appropriate sampling acknowledged the diversity of teacher participants and their experiences to support transferability in findings. The interviewed teachers represented diversity in teaching content areas, grade level taught, student achievement levels, and school demographics. The second sample of teacher interview participants were selected to complement the previously interviewed subject group (Morse et al., 2002; Noble & Smith, 2015).

Initial coding was conducted using the pre- and post-workshop interviews with the electrical engineering workshop participants. Two researchers interpreted and coded transcripts until a clear coding scheme was developed. Reliability of the qualitative component of this research was established through interrater agreement. Coders independently coded transcripts and later compared results for agreement in coded passages and attributed codes (Creswell, 2013). Discrepancies in coding were resolved through negotiated agreement to maximize reliability (Campbell, Quincy, Osserman, & Pedersen, 2013). Emergent themes from the first workshop interviews were used to guide questioning during the biological engineering workshop phase of data collection, providing rigor through methodological coherence (Morse et al., 2002; Noble & Smith, 2015). Through this iterative evaluation process, developing themes were confirmed and further explored through later interviews (Morse et al., 2002).
Chapter 4

Results

4.1 Introduction

Following their involvement in a multi-session professional development workshop in engineering practices for science educators, this convergent parallel, mixed methods study investigated three questions about the impact of this professional development experience on teachers and their beliefs regarding the integration of engineering in their science courses:

1. How does professional development in engineering education affect secondary school science teachers’ beliefs about the value of using engineering design to support science learning?
2. How does professional development in engineering education affect secondary school science teachers’ self-efficacy regarding teaching engineering in their science courses and providing advisement for engineering careers?
3. What obstacles do science teachers identify during the implementation of engineering practices in their science classes?

This chapter presents the results and findings of the comparison of pre-workshop and post-workshop data to assess the impacts of an engineering professional development experience on science teachers’ knowledge and skills related to teaching engineering. In Section 4.2, the quantitative results from the analysis of teachers’ survey responses are presented and emergent themes in teacher growth are identified. Profiles of the six interviewed teachers and their school districts are presented in Section 4.3. Section 4.4 describes the qualitative findings within five themes which emerged from interviews with teachers: 1) pre-workshop vision of engineering, 2) motivation to integrate engineering instruction, 3) teaching engineering confidence, 4) encouraging engineering futures, and 5) obstacles to integrating engineering. Finally, a summary of triangulation between quantitative results and qualitative findings is presented in Section 4.5.

4.2 Quantitative Results

Overall survey results.
The Engineering Professional Development Survey used in both the pre- and post-professional development surveys had a high internal consistency (Cronbach’s $\alpha=0.945$). Teachers responded on a six-point Likert-scale (1=strongly disagree to 6=strongly agree), self-assessing their ability to accomplish the tasks related to engineering pedagogy and advisement. To improve external validity, the pre-survey composite scores of the treatment group ($n=32$) were compared to a control group ($n=28$). A priori power analysis (G*Power 3.1, Faul, Erdfelder, Lang, & Buchner, 2007) indicated a combined sample size of 42 was required to detect a large effect with 80% power. Independent-samples t-tests indicated no differences between the two mutually exclusive groups
(t=1.180, \(df=58\), \(p=0.243\)) on the pre-survey \((M_{control}=83.86, SD=16.59; M_{treatment}=77.78, SD=22.37)\). This showed that the teachers in the treatment group were similar to the general population of teachers in New York State in terms of engineering knowledge and skills, pedagogical content knowledge, and ability to differentiate engineering disciplines.

To measure the effectiveness of the engineering professional development, a paired-samples t-test was conducted with the treatment group \((n=21)\) to compare mean composite survey scores before and after the workshop. A priori power analysis indicated a sample size of 19 was required to detect a large effect with 80% power. The teachers significantly improved their self-assessed engineering knowledge and skills \((t=4.652, df=20, p<0.001, 95\%CI[13.8, 36.2])\) from pre-survey \((M=75.29, SD=26.11)\) to post-survey \((M=100.29, SD=12.69)\), with a large effect size \((d=1.22)\). The teachers improved their self-assessed ability to teach engineering, develop a productive classroom environment for engineering engagement, and advise students on preparing for engineering study and careers; their mean scores on nearly every survey item increased significantly from pre- to post-workshop, as indicated in Table 7. The only area in which teachers demonstrated no statistical self-reported growth was in their ability to modify their existing curriculum to satisfy the NGSS objectives.
Although teachers significantly improved in many areas of engineering knowledge and instruction, the effect sizes ranged from medium ($d=0.61$) to large ($d=1.28$). The teachers reported very large improvements in their ability to: 1) use engineering activities in the classroom effectively, 2) increase students’ interest in engineering, 3) help students apply engineering to real-world situations, and 4) advise students on different engineering disciplines and careers, as well as how to prepare for them before college. The one item that was not significant was their reported ability to modify their curricula to comply with NGSS. Consequently, the researchers felt an additional workshop session might be warranted to focus specifically on curriculum writing and alignment. Most teachers administered state standardized culminating exams in their content areas,
which had not yet been re-aligned to NGSS. This constraint may have impacted their confidence in making curricular changes before the exam items reflected NGSS expectations.

**Exploratory factor analysis and thematic comparisons.**
A subsequent exploratory factor analysis with Varimax rotation was performed to identify thematic subscales in the *Engineering Professional Development Survey*. The sample size met the criteria proposed by Mundfrom, Shaw, and Ke (2005). As indicated in Table 8, results from the principal components analysis suggested the presence of two constructs. These two subscales – 1) engineering pedagogical confidence, and 2) engineering career awareness and advisement confidence – accounted for 52% and 13% of the variance in composites scores, respectively. Paired samples *t*-tests were analyzed to determine within-group differences on these two specific scales, as way to determine workshop effectiveness in two specific areas. For factor 1, teachers significantly improved their engineering pedagogical confidence (*t*=4.442, *df*=20, *p*<.001, 95%CI[10.89, 30.16]) from pre-survey (*M*=63.95, *SD*=21.43) to post-survey (*M*=84.48, *SD*=11.72), with a large effect size (d=1.19). For factor 2, teachers significantly improved their engineering career awareness and advisement confidence (*t*=4.755, *df*=22, *p*<.001, 95%CI[2.48, 6.31]) from pre-survey (*M*=11.35, *SD*=4.83) to post-survey (*M*=15.74, *SD*=2.49), with a similar large effect size (d=1.14).

**Table 8. Exploratory Factor Analysis of Thematic Constructs**

<table>
<thead>
<tr>
<th>In my role as a teacher, I am able to… (n=21)</th>
<th>Factor loadings</th>
<th>α = .954</th>
<th>α = .877</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINEERING PEDAGOGICAL CONFIDENCE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Explain engineering concepts well enough to be effective in teaching engineering.</td>
<td>.829</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Assess students’ engineering products.</td>
<td>.738</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Employ engineering activities in my classroom effectively.</td>
<td>.869</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Explain the ways engineering is used in the world.</td>
<td>.837</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Describe the process of engineering design.</td>
<td>.865</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Create engineering activities at the appropriate level for my students.</td>
<td>.886</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Select appropriate materials for engineering activities.</td>
<td>.826</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Recognize and appreciate the engineering concepts in my subject area.</td>
<td>.759</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Guide my students’ solution development in learning the engineering design process.</td>
<td>.816</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Increase students’ interest in learning engineering.</td>
<td>.562</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Help students apply their engineering knowledge to real world situations.</td>
<td>.774</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Promote a positive attitude towards engineering learning in my students.</td>
<td>.592</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Encourage my students to think creatively during engineering activities and lessons.</td>
<td>.804</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Encourage my students to think critically when practicing engineering.</td>
<td>.727</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Encourage my students to interact with each other when participating in engineering activities.</td>
<td>.664</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Modify my curriculum to comply with the Next Generation Science Standards (NGSS) and/or the New York State Science Learning Standards (NYSSLS).</td>
<td>.684</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Acquire the resources for implementing NGSS and/or NYSSLS.</td>
<td>.683</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ENGINEERING CAREER AWARENESS AND ADVISING CONFIDENCE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Inform my students about engineering careers.</td>
<td>.768</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Differentiate between engineering disciplines.</td>
<td>.878</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Recommend relevant high school courses to students interested in pursuing engineering.</td>
<td>.795</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Profiles of Interviewed Teachers

The six teacher participants who volunteered for interviews were all recruited through their involvement in the Master Teacher Program as both workshop series were offered in conjunction with the NYSMTP. Each teacher had at least ten years of teaching experience. Each was employed in a different school district located within 50 miles of each other in New York State and each teacher had a unique background in certification content area and teaching experience.

**Pedro.**
Pedro, a participant in the electrical engineering workshop series, taught accelerated eighth grade students taking the New York State Regents course in Earth Science as well as an introductory course in science research, also intended for advanced middle school science students. In addition to his teaching responsibilities, Pedro served as a chair for his school’s science department. In this capacity he facilitated department meetings and coordinated teacher and course scheduling, among other administrative tasks. Pedro was employed in an economically stable district (10% of students are economically disadvantaged) located in a community very close to the university hosting the workshops (NYSED, 2018). He was very familiar with the learning labs and associated outreach offered at the university as he had previously taken students on field trips to utilize these services.

**Joseph.**
Joseph was employed as a physics teacher in a school district that was demographically very similar to that of Pedro. His district also serviced a relatively small population of English language learners (2%) and underrepresented minorities (7%) compared to the state distribution (9% and 47%, respectively) (NYSED, 2018). At the high school level Joseph was teaching Advanced Placement Physics for junior and senior students and an interdisciplinary aeronautics elective course that he taught in conjunction with an engineering teacher. Joseph participated in the electrical engineering workshops.

**Jack.**
Jack taught the NYS Regents Physics course for junior and senior students. Prior to attending the electrical engineering workshop, Jack had experience teaching engineering as an instructor of an introduction to engineering design course at his school. Jack demonstrated more confidence than his peers regarding his ability to teach engineering prior to the workshops because of his involvement in this elective course. Jack’s district was very similar in demographics to both Pedro and Joseph’s schools. All three were consistent in size and had a relatively low population of English language learners (1%) and economically disadvantaged students (12%) (NYSED, 2018).

**Lydia.**
Lydia taught the New York State Regents Living Environment course at a middle school. Lydia’s district had adopted an “acceleration-for-all” program in which all of the eighth grade students in the district were enrolled in this biology course, although the course was typically offered throughout the state to ninth or tenth graders. Lydia’s district demographics very closely matched the distribution of students throughout New York State. Her district served a relatively large number of underrepresented minority (51%) and economically disadvantaged (65%) students (NYSED, 2018). At the start of the workshops, Lydia was the least comfortable with engineering design. She participated in the electrical engineering workshop series.
Sophie.
Sophie taught Advanced Placement Biology for junior and senior students and Regents Living Environment for sophomores in a very large suburban school district. The needs and priorities in Sophie’s district were unique compared to those of the other teacher participants in either workshop. Sophie’s district served a very high proportion of underrepresented minorities, particularly Hispanic and Latino students (84%) with limited English proficiency (33%). She explained that many of the students in her school were itinerant and frequently missed school for lengthy periods of time. A large proportion of Sophie’s students were from economically disadvantaged families (89%) and funding for resources in her school was severely limited (NYSED, 2018). Sophie attended the biological engineering workshops.

Richard.
Richard, a participant in the biological engineering workshop series, taught Advanced Placement Biology with junior and senior students and a science research elective for ninth and tenth graders. With the research class, Richard had worked closely with a national research laboratory located not far from his district. Richard’s district served a minimal number of economically disadvantaged students (20%) and English language learners (2%) (NYSED, 2018). Like Pedro, Richard had experience in the university learning labs taking his own students on field trips to do structured activities.

4.4 Qualitative Findings

The pre- and post-workshop interviews with select participant teachers provided greater insight into the attitudes and experiences of science teachers in the process of undertaking engineering instruction. Additionally, teachers expressed their concerns about the continuing obstacles they faced as they attempted to implement engineering in their classrooms. Through the process of coding, five distinct themes emerged: 1) teachers’ pre-workshop vision of engineering, 2) teachers’ motivation to integrate engineering, 3) teachers’ confidence to teach engineering, 4) teachers’ awareness of engineering futures, and 5) teachers’ perceived obstacles to integrate engineering. Each of these themes are related subthemes are outlined in Figure 3.
Figure 3. Emergent themes in pre- and post-workshop interviews.

**Pre-workshop vision of engineering.**
The ability of teachers to implement engineering effectively in their science classrooms requires that they have an understanding of engineering and how it is framed in the NGSS. This was addressed in both workshops. In pre-workshop interviews, teachers described their previous experience with engineering that shaped their perception of the subject as well as their awareness of the state science standards specifically associated with engineering. Prior to the workshop series, teachers generally identified engineering as the application of science knowledge through problem solving but very few were familiar with components of the engineering design process. All of the teachers had attended previous professional development focused on the NYSSLS but all felt unprepared with regard to the engineering standards prior to their participation in the workshops. The major subthemes representing teachers’ experience with engineering and the NYSSLS are represented in Figure 4.

![Figure 4. Theme 1: Pre-workshop vision of engineering.](image)

**Definition of engineering.**
Before attending the workshop series, science teachers’ definitions of engineering were largely shaped by their informal experiences in different contexts. Only one of the interviewed teachers, Joseph, identified having specific education or training in the field of engineering. Another teacher, Jack, was, at the time of the workshop, teaching an elective course in engineering and had received extensive training specifically on the course curriculum. All but one of the teachers, Richard, described their experiences in engineering as a hobby or related engineering to repairing items around their home or workplace. Four of the teachers attributed much of their awareness of engineering to a relative or friends’ pursuit of a degree or career in some field of engineering.
Consistently, teachers described engineering as “problem solving” when asked for a definition in the pre-workshop interviews. For some of the teachers, their vision of engineering specifically involved “making something” or “developing things” to address an identified problem. Richard, a biology teacher, articulated his understanding of the traditional definition of engineering and how the practice of engineering had grown to be applied to solve problems in many science disciplines. The traditional examples he provided were related to mechanical engineering and design, while the more modern examples related to biotechnology:

My perception of it is, it involves either constructing something, either physically or through modeling, it could be computer-based. You know, it could apply to a lot of different fields. I think the original idea of engineering was buildings and construction, but now we know with engineering, we can do things like creating genes and creating proteins.

Richard’s perceptions revealed a view of the evolving nature and importance of engineering in modern day science. Two other teachers made an association between science and engineering without being probed specifically about the integration of the fields, however, their understanding was focused exclusively on physics. This demonstrated a somewhat limited view of how science and engineering principles could be applied in developing technological advances. For Joseph, a physics teacher, engineering was closely associated with innovation and specifically involved the application of physics knowledge, as he stated:

So, I think of engineering as applying the physics principles to make the world a better place; whether it mean like a better watch, a better phone, a better - whatever - but to use the ideas that we learn in physics and apply them to real world situations.

For many of the teachers, their vision of engineering was contextualized in their own domain of science study and teaching. Some teachers did make reference to other STEM domains in their definitions, stating that engineering uses “science and technology” or speaking of “all the math involved.”

The iterative nature of engineering was emphasized in one teacher’s definition, as she shared her thoughts that “engineering is so much about failing and fixing things” and that “in engineering, you’re going to continuously be retooling things.” This teacher recognized the design process is typically non-linear, often characterized by failures and continuous modification before achieving an optimal product. The other teachers did not make reference to the formal engineering process in their initial definitions.

**Familiarity with NYSSLS.**

Prior to the workshops, the interviewed teacher participants all acknowledged having extensive training in NGSS as adapted for New York State (NYSSLS) as part of their involvement in the Master Teacher Program. For all of the teachers, their participation in the Master Teacher Program was a significant factor in their acquisition of knowledge regarding NYSSLS as well as their reflection on their experience in the workshops and the implementation of the standards in their classrooms. Some of the teachers had also engaged in NYSSLS-related staff development in their own school districts.
While they were confident with their understanding of the structure of the document (i.e., cross cutting concepts, disciplinary core ideas, science and engineering practices) and the skills associated with the science practices, all of the teachers admitted a lack of awareness of the specific engineering standards that were meant to be intertwined with the science content and practices. Jack explained, and most of the teachers echoed, “I would say that besides engineering, which we haven’t really touched on, we’ve been getting - I would say pretty extensive PD [professional development] on the new standards.” According to the teachers, these prior professional development opportunities were focused on the science practices, such as questioning, modeling, argumentation, and explanation. Pedro reiterated this point in the post-professional development interview:

Especially right now, but if you’re trying to juggle teaching people the standards and thinking of ways to use it. The engineering unfortunately, is likely to take a backseat to the science.

This point was illustrated prior to the workshops by the inability of all six teachers to identify the specific NYSSLS engineering standards for their grade band or how those standards were associated with their course content. Of the engineering standards, some teachers said, “I’m completely unaware of that,” or “I couldn’t name them without looking at the document.” This highlights a significant deficiency in the availability of opportunities for science teachers to develop engineering content and pedagogical content knowledge.

Sophie demonstrated a holistic understanding of the NYSSLS. When asked about her interpretation of how the elements of the standards fit together, she alluded to the intent of the standards to provide a more cohesive education through the K-12 science course sequence, as well as between science and the content students are learning in their other courses. She explained that the new standards provided more structure to enable her students to draw connections between their mathematics coursework, their prior middle school science classes, and their high school biology class, which she was teaching at the time:

I guess what they’re looking for is to make science so it’s a continuous spectrum and so it’s not disjointed and so the kids understand that the math they’re learning and the biology they’re learning, and the - it all goes together. And the engineering, I think, is kind of the thing that ties everything together. I think between the - we always joke in biology - the kids are like, “Oh, but I know how to graph in math.” So it’s more like that we’re concerned about the concepts and that the concepts - what you’re learning in seventh grade life science isn’t disconnected.

Sophie’s awareness of the standards and the mission of the NGSS documents was the exception, as most teachers did not describe the standards as cohesively. The other teachers’ responses to the same questioning demonstrated a disconnect between the science and engineering practices, suggesting they perceived the NYSSLS engineering standards to be supplemental to the science standards, rather than integral.

Prior to the workshops, the interviewed science teachers had limited experience with engineering and possessed often over-simplified views regarding the process of engineering shaped in part by misconceptions regarding the definition of engineering. In pre-workshop interviews, the teachers demonstrated a lack of awareness of the engineering standards of the
NYSSLS and therefore were likely to have thus far foregone the implementation of engineering in order to emphasize the science practices in their classrooms. This initially limited familiarity with engineering left much potential for teachers to experience growth through this short-term professional development experience.

**Motivation to integrate engineering instruction.**

The teacher participants in both workshops were all highly motivated teacher leaders. They had been recognized as Master Teachers because of their commitment to their profession and the success of their students. Their involvement with the program required attendance at regularly scheduled meetings as well as additional professional development activities each year. As discussed earlier, each of the interviewed teachers attributed their awareness of the NYSSLS to the opportunities offered through the Master Teacher Program. Following the workshops, the Master Teacher disciplinary meetings provided opportunities for continued teacher growth.

One of the participants in the electrical engineering workshop explained how the workshop lead to ongoing conversation in the physics Master Teacher meeting, saying “it was a springboard to how do we convert things that we really know how to teach cookbook-style and are very valuable and important, but how do we convert it to this new style of NGSS learning?” Despite many of the interviewed teachers not receiving encouragement or support for NYSSLS implementation from their districts, these teachers were independently motivated to make efforts to adopt change. In both the pre- and post-workshop interviews, the teachers demonstrated intent to integrate engineering into their science courses for the benefit of their students. Prior to his participation in the biological engineering workshop, Richard expressed the sentiments reflected in most of the teachers’ statements about engineering and their goals for the workshop series:

> I don't believe I infuse enough of it into my course. So I would like to get that connection for my students. Because then it gets into another area that can open new horizons for them. So I know engineering is a big piece of that so I would like to get myself a little more comfortable with that so that my students, in turn, had that experience, too.

For all of the teachers, the potential positive impact of engineering instruction on their students was the primary motivating factor for their participation in the workshops and their efforts to develop their own knowledge of engineering. Based on the teachers’ previous statements acknowledging their lack of familiarity with engineering and statements like Richard’s, it was evident that prior to the workshops, teachers expressed a desire to incorporate engineering instruction but lacked the confidence or awareness to do so effectively.

The teachers expected that including engineering instruction in their courses would have numerous positive outcomes for students, including increasing interest and achievement in science and awareness of career options in engineering. Despite their perceived value of engineering in the classroom, the teachers received varying levels of support from their school districts and colleagues for adoption and implementation of the NYSSLS. This theme and related sub-constructs are represented in Figure 5.
Value of engineering in the science classroom.

The teachers all recognized a significant benefit in embedding engineering within their science instruction. All six of the interviewed participants were eager to describe their perceived value in being able to engage their students in engineering activities in their course. Interestingly, the focus of the teachers’ anticipated benefit to students in incorporating engineering shifted during the workshops. In pre-workshop interviews, teachers tended to emphasize the value of engineering in increasing student interest and engagement in their science coursework. While that theme was represented following the workshop series as well, teachers’ perceptions of the power of engineering instruction focused more on the benefits to students in improved learning experiences through the application of science knowledge, developing science “thinking” and skills, and awareness of potential career opportunities in engineering fields. All of the teachers provided a richer description of the value of engineering in their science courses following their participation in the workshops.

Interest in science.

Increased student engagement and interest in science was the most frequently referenced benefit to integrating engineering instruction prior to the workshops. The theme was repeated in post-workshop interviews but with less emphasis. Nearly all of the teachers saw the inclusion of the engineering design process as a means of supporting their science content instruction. Teachers anticipated that the novelty of engineering activities would “grab students’ attention” and get students to “buy-in” to a more engaging presentation of science content offered as an engineering challenge. Before the workshops Joseph explained, “I think it would increase student interest and get them to see why we like science.” Pedro, an Earth science teacher, expressed the same thoughts:

Then it's a hook and then they can start to see that and why it makes sense to have knowledge of the sciences and engineering and mathematics or even working on simple designs now. So it's a good motivator.

Both of these teachers, and several of the other participants recognized that engineering activities could be used to support the development of student science content knowledge by providing an application component that was sometimes missing from their curricula. Teachers believed that students would be more likely to relate to their science course content if it were applied in an engineering design problem with real-world relevance.

Following the workshops, Joseph enthusiastically described his experience working on the night light activity during the electrical engineering workshop:

I thought the biggest takeaway for me is that, when you combine the science and the engineering together, it gets so much more interesting. If it was just that we
built that light the first time that changed colors, it would have been a light that changes colors. But then to think about how it's changing colors because it's a combination of the three primary colors and that there are certain colors you can never make, that your eye can still see but you can't make them with these, and then now I look at my TV and I'm like, “I paid a lot of money and it can't produce all the colors possible.” So combining those two, I felt, made that lesson a lot more interesting and that's something I would try to do in my classroom.

This teacher recognized that both the science and engineering instruction were augmented by the union of the two in the classroom. Through his own experience he saw that by integrating the science content with an engineering application, a lesson could be enriched and made more engaging for students. Another teacher said post-workshop, “I think the science will benefit from the engineering and vice versa.” When considering the specific NYSSLS, teachers tended to isolate the engineering standards from the science standards but when discussing the value of engineering to science, all of the teachers identified a distinct connection. This association between science and engineering was more pronounced in the post-workshop interviews.

Several of the teachers related the increased interest on the part of students specifically to the authentic “real world” applications of science knowledge that are associated with engineering activities, as Joseph described in the previously referenced quote about the night light activity inspiring him to think about how his television displays color. Pedro identified with this theme as well during in his reflection of the workshop:

I think it provides us that real-world application. It provides a sense of necessity to have the knowledge base. You know, you need the knowledge to design a solution. So it presents it in that fashion. It doesn't present it as ending in an exit exam or anything like that. It's a little bit bigger, if there is the buy-in. So students are actually interested in – because if it's presented as a way to turn it in and it is completed, then it's not much different internally. But if there is a little bit more authenticity to the problems that are crafted around an application to more of a scenario-based approach for a problem.

Like Pedro, many of the teachers anticipated that students would attribute more value to their science learning if they identified relevance for the content material in their own lives and experiences. By making this connection for students, teachers felt they could more easily engage students and motivate them to invest more effort in their learning as well as develop a greater sense of purpose for learning. During the post-workshop interview, one physics teacher said, “It becomes less about learning facts and doing well on tests and more about solving problems and making the world a better place.” Both of these teachers hoped that the inclusion of engineering would encourage students to reevaluate their motivation for learning. Nearly all of the teachers expressed concern about the emphasis their students placed on grades and standardized test scores. This will be discussed later in more detail as an obstacle to engineering integration. The teachers hoped that by making science more relevant through problem-based engineering activities, students might perceive more value in the learning process and place less emphasis on the grade associated with completing the task.
Exposure to career options.

In both pre- and post-workshop conversations, several teachers anticipated that by making real-world engineering connections in their science courses, they would empower students with awareness of career opportunities in preparation for their futures. A primary objective in the development of NGSS, which was based upon the Framework for K-12 Science Education, was to encourage students to pursue careers in STEM fields with high anticipated vacancies (NRC, 2012). Time was spent in both workshops to inform teachers of the educational pathways in engineering beyond high school and the career options that could follow. Teachers expressed appreciation for this aspect of the workshops and had thoughtful reflections regarding the conversation. Following the electrical engineering workshops, Joseph hoped that by exposing his students to unique engineering experiences in relevant contexts, he could inspire more students to develop a passion for both science and engineering that might lead to a career choice in the future:

I think my motivation is to get them to see what an impact they could have on the world by designing solutions. And if you can do that within the physics classroom, I think you might get a few more kids who want to go into science and engineering, and it's not all about the money.

Sophie also identified a future value to her students in exposing them to engineering in her science class. Sophie took a broader perspective; she had been motivated to encourage students to consider engineering as a career option by her awareness of the current trends in the job market and U.S. economy and society. Sophie had reluctantly admitted to encouraging students who were interested in pursuing biology majors to consider an engineering field instead for the greater potential job placement in the future. After the workshops, she said,

When you look at the jobs and the forecasted and suggested jobs, we're actually producing way more biologists than we have jobs for. We're not producing anywhere near enough computer people, engineers, those kinds of things, for what we have jobs for. If the end goal of education is to get people to move into the work force, it seems to me we're doing things all wrong. We're not matching jobs with curriculum. I know some of the end goal is to make a democratic society, but it's also to get a sustaining society. When you look at the engineering jobs, there's way less projected graduates, to the point where I think the study I was looking at said we don't even have the capability of educating the engineers we're going to need. We don't have programs set up in college to do that at this point. This is more like way behind the game where we should have been. If we're going to stay on top, United States, as innovation and this and that, then we really have to switch focus.

Sophie wanted to be a resource to her students in planning their futures. She hoped that by exposing her students to engineering and related career fields and helping them to develop the necessary science and engineering skills in her biology course she would inspire them to consider pathways they had not been aware of previously. For Sophie, this mission was particularly important as she explained that the parents of many of the students in her school community were not college-educated and were not able to provide guidance to their children about opportunities in engineering and other STEM fields.
Science skills development.
Highlighting another benefit to students, some teachers saw engineering as a powerful tool in developing students’ critical thinking and problem-solving skills. As discussed earlier, the NYSSLS framework emphasized the practices of science and engineering alongside the instruction of science content. This focus on skills development presented a novel challenge for teachers as these practices were not central to previous versions of the state science standards and teachers were unfamiliar with the pedagogical strategies associated with teaching science this way (NYSED, 1996, 2016b). The biology teachers, in particular, identified engineering instruction as a mechanism for developing students’ analytical skills. Even before the workshop series, Lydia said, “I do value it, actually. I think it makes the kids critically think about things themselves, not be handed solutions and that they have to also listen to each other.” After her participation in the electrical engineering workshops, she more clearly articulated the same beliefs:

Taking what they know and applying it to a new application, thinking things through, following a design plan, when it comes to an experiment, following that, critically thinking and assessing – just so many skills I see. And then just really higher level thinking.

Following the workshops, Lydia was able to demonstrate an improved understanding of the elements of the engineering process as well as how it could support the development of essential science skills. She anticipated that through engagement in unique engineering tasks, like those demonstrated in the workshop, students would develop more as scientists as well as engineers.

Other teachers demonstrated similar growth in thinking following the workshop series. Prior to the workshops, Richard expected that engineering would support the development of science skills but he spoke very generally without describing specific ways in which students would demonstrate growth:

I think engineering lends itself to kids thinking outside of the box and coming up with, you know, how does something work? How can they figure this out? I think there's more than one way to solve a problem with engineering. So I think that connects to the whole claim evidence reasoning piece and I think that's also going to lend itself, with the crosscutting concepts, that you have an engineering activity you are working on, that's going to naturally bring in these other skills and concepts that will fit across the board.

After his experience in the biology workshop, Richard demonstrated a more refined understanding of the engineering design process, as well as a more definitive connection to specific science skills, such as communication, collaboration, analysis, and asking questions. After the workshops, he elaborated:

It's going to allow kids to be just better thinkers. It's going to help them become more active and engaged in the learning process. When you start bringing in these engineering processes, and like you say, have this analysis, and you have this whole process of optimizing and doing all of that, I think kids become more engaged with each other. I think there's more conversation in the classroom. I think there's more interaction. I think it also allows them to think a little bit more openly. So the sky's
the limit, so to say, for them. I think we're not just being held to "We have to stay within these confines of content because we need to move ahead and move forward." I think it will make it more engaging. Getting them up and moving around and doing more on their own, versus me being the sole source of information.

While they had some sense of how engineering could enhance science thinking in their students before the workshops, these teachers demonstrated a more concrete relationship between the science and engineering practices following their direct participation in the workshop activities. These teachers identified specific science skills that would be supported with engineering instruction, such as asking questions, developing and using models, planning and carrying out investigations, constructing explanations, and engaging in arguments from evidence.

For many of the teachers, engineering provided a unique contextual foundation for their science teaching. Teachers expected that the novelty of the engineering experience for students would increase student engagement in the process of science. In his post-workshop interview, Richard described how this deviation from the typical science lab would support student learning:

It promotes greater critical thinking and analysis for kids. It also gives them a chance to look at something in a different way from your standard lab format. Here's something new. This is something presented in the context of something you haven't seen before, but the end result is still the same. Here's the system. How are the variables in that system impacting it? What would happen if you changed something? How could you make that better? What's the impact of something new being added to it? I think this ties in really well with what we want kids to do as far as analyzing it, not just memorizing, but actually being able to problem solve. It’s problem solving.

Richard expected that in applying his science knowledge through the engineering design process, students would take a more active role in their learning. Through designing, testing, and optimizing solutions to practical problems, Richard anticipated that his students would develop a greater understanding of science from a systems perspective. This aligns with NGSS since “systems and system modeling” is one of the crosscutting conceptual themes in the new standards (NGSS Lead States, 2013). While Richard acknowledged familiarity with the NYSSLS format prior to the workshops, this was the first time he identified a specific crosscutting concept and its relevance to engineering.

The teachers wanted to be able to offer their students more opportunities to engage in the process of science, something they felt was sometimes lacking from their previously existing curricula. They anticipated that modeling classroom activities on the engineering design process would provide the foundation for the development of these skills in a unique context. After experiencing several engineering tasks during the workshops, teachers demonstrated a clearer sense of the relationship between engineering and science in the classroom.

Improved science performance.
All of the interviewed teachers were invested in their students’ becoming more knowledgeable in the science content and practices. Ultimately the teachers were optimistic that the inclusion of engineering would provide a benefit to their science instruction by increasing student achievement. Jack summarized this belief:
It would be an application of the physics that we’re learning which would hopefully – even if it just exposed the kids to more practice of that physics if we’re doing a project on a projectile and they have to do a bunch of projectile physics over and over again while they're trying to perfect a launcher, then they are doing physics without even realizing it, maybe. And so they're practicing it more and I think when something seems important or seems practical, people might learn it better or pay more attention to it. So, they might learn physics better if we’re not learning it because this is what [my teacher] said, this is what we’re learning this week; we’re trying to solve this problem and in order to do that we need to learn about forces or projectile motion or something. So they might take a little more ownership over their learning because they're actually planning on using it. It’ll make it seem more important and more real and more applicable.

The teachers expected that the combination of increased student engagement in unique problem-based engineering tasks with practical relevance would improve student learning of the science content and how it could be applied in these contexts. It was presumed that the iterative nature of the engineering process would enable students to develop their science knowledge through repetition and the structure of the engineering task would provide opportunities for students to acquire the skills associated with the practice of science.

Overall, teachers expressed high valuation of engineering with regard to student interest in science, in both the short and long term. This group of teachers was clearly invested in becoming more aware of teaching engineering, in part, to inspire their students’ appreciation for both science and engineering. Following participation in the workshops, teachers demonstrated an increase in the perceived value of engineering education in their science classrooms. It is anticipated that this augmented worth would provide increased motivation for teachers to include elements of engineering in their lessons, and ultimately increase the likelihood of implementation.

**NYSSLS implementation.**

While all located in the same geographic region, each of the interviewed teachers was employed at a different school district with unique priorities, needs, and student demographics. Similarly, the adoption of NYSSLS-aligned science programming varied widely among districts. Some districts had already made notable investments in implementing the latest science standards, while other districts had not yet made efforts to reform their science programs. In any case, teacher workshop participants demonstrated initiative in driving innovation in their science departments. No significant shift in district adoption of NYSSLS was noted during this investigation, likely due to the limited time elapsed between the pre- and post-workshop interviews (approximately three months).

**District curriculum change.**

Four of the six interviewed teachers were working in districts that had made at least some commitment to the implementation of the new state science standards, although the degree of investment varied among school districts. Pedro was employed in what seemed to be the most progressive district, and he described plans to roll out curriculum change progressively starting at the lower levels:
We are being proactive. We are pushing ahead. We're not ignoring it. So I'd say kindergarten and grades one and two right now are teaching to the new standards – ideally. Then seventh grade next year will be having a summer curriculum project with a changing curriculum; eighth grade the year after.

Pedro worked in a district that was financially stable and well known for their rigorous academic programming. Resources had already been committed to adjusting curriculum at various levels throughout the district. He also described a novel approach his district was taking in the reform process, with secondary science teachers taking a role as “elementary science consultants.” In this district, secondary science-certified teachers were scheduled to spend some part of their day working in the elementary schools where they collaborated with elementary teachers to develop curriculum for the primary grades and assist in classroom lessons. In doing this, the district hoped to provide necessary science content support to non-science specialized elementary teachers as well as ensure articulation in the K-12 science program. The choice for some districts to begin NYSSLS implementation at the elementary level was likely related to concerns raised during the adoption of the Common Core standards for math and English language arts several years prior (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). The simultaneous multi-grade level roll out of the revised math and ELA standards and assessments created challenges for state policy-makers and frustration for parents, students, and educators, something New York State and local districts seemed to be trying to avoid during the implementation of NYSSLS (Kober & Rentnor, 2012; Pense, Freeburg, & Clemons, 2015; Wankmuller, 2019).

In Sophie’s district, roll out had also begun at the elementary level but she was concerned that the support would be lacking for teachers to make effective use of the curriculum program in the primary grades. She was frustrated her district was not receptive to a model like Pedro described:

The problem is I know that this is happening at the high school level. But it seems like that's not necessarily where it should be starting. So because there's no vertical teaming, I don't know what's happening at the – and we even offered, because the elementary schools go later. So the high school teachers said, "If you're getting these Pearson kits or whatever you're getting to rollout" several of the teachers were like, "If you'd like, we'll go down – because we're out at 2:00. So if you'd like us to go down when the teachers – "Or explain the science background for it or what, if the elementary school teachers are uncomfortable. But because there's no vertical teaming, we have no idea. Part of that's size. We have 13 elementary schools. We have four middle schools. And a lot of it it's just there's no central – the person that's in charge of science and math education.

Aside from the purchase of pre-packaged science curriculum kits for the elementary level, Sophie’s district had made no other organized effort towards NYSSLS alignment. Teachers had not been provided with professional development to ensure the resources were being used properly. Sophie was worried the lack of motivated leadership and communication in her district would be a significant barrier to the successful implementation of the standards. Sophie’s district was less financially stable and had a large migrant student population, making continuity of instruction difficult. She was concerned that students would not arrive to her high school course
prepared with a sufficient familiarity with engineering to allow her to implement tasks that would appropriately align to her biology content.

In other districts, the efforts seemed less formalized. Although these districts were providing staff development in the NYSSLS, teachers reported a lack of administrative supervision at the classroom level. It is likely that without teacher accountability, classroom implementation would be limited. Jack felt that after investing in staff development and NYSSLS training, his district expected implementation to be occurring. However, he did not feel these efforts were sufficiently monitored by his administration:

I think that our science director also just expects that we're doing, you know, implementing some of the practices in our classrooms. I don't know that we're necessarily being held accountable to that yet, but we're getting the training on it and I think she expects us to do that, you know, do modeling and QFT [Question Formulation Technique]. I mean, that's really all we can do now since we're not, you know, the content isn't any different than it used to be. We're getting used to implementing the practices as much as we can.

Jack’s district had invested in teacher training during staff development days and department meetings, including sponsoring presentations from an expert in NGSS implementation. As Jack explained, there was an implied expectation of implementation but no formal classroom evaluation was occurring. Similarly, Lydia observed in her district that there was no accountability on the part of teachers making changes in their courses and therefore the impact on students through change in pedagogy was limited. She said, “We are doing a lot of professional development to implement it, but has it gone into the classrooms? No, definitely not.” She explained that she and some of her colleagues were making efforts to align to the NYSSLS but no formal curriculum revision had occurred in her district.

Teacher adoption.
Particularly in districts where there had been little to no district effort toward alignment, many of the teacher participants in this study had taken initiative in this reform. This was not unexpected given that these individuals were recognized as Master Teachers, in part, because of their previous leadership experience. Several of the teachers identified positive experiences with colleagues collaborating to develop and carry out NGSS-aligned activities in their courses both before and after the workshops. This model for collaboration was employed throughout the workshop series as teachers worked in pairs and small groups to conduct the engineering activities or converse about classroom implementation strategies. Teachers responded positively to the “ability to actively be involved, creating with peers,” as one participant described it.

In her pre-workshop interview, Sophie described how she was regularly engaging with her colleagues, “we've been meeting for the last two years as individual teachers on our own…the third Tuesday of the month, we meet to talk about NYSSLS as just teachers.” Despite the lack of initiative at the administrative level, Sophie and her colleagues were highly motivated to invest in NYSSLS-alignment. She added:

Several of our teachers have paid with their own money to get the NYSSLS training. They've gone to weeklong workshops. And so I would say that – multiple
teachers, I would say more than 10 or 12, have – are paying with their own money to address the standards.

Sophie’s experience demonstrates the value of professional development targeted to teacher-influencers. She was very likely to take her experience from the biological engineering workshop to share with her colleagues in her own professional network, increasing the number of students who might benefit from her participation.

Lydia was inspired through her participation in the workshop to develop new activities to include in her biology course. In one lesson, she presented the students with a challenge to envision a way to support productive farming in a region with a typically cold climate like Iceland. Her students discussed the requirements for photosynthesis and ultimately devised a greenhouse-like structure with a carbon dioxide pump to provide the gas necessary for carbon fixation. After implementing the lesson successfully in her classroom, Lydia shared it with another teacher:

The lesson that I did with the photosynthesis, I shared that with a colleague and she also ran it. And she was thrilled to be able to — because we are very NGSS-minded, which is great that I have great colleagues like that, who aren't Master Teachers and still want — and she was like, "I so want to start integrating more of that modeling" and so she was super on board with that. It's hard to get people — I've tried myself, trying to get people to try. And once they try it, they're like, "That was really great," like with lots of NGSS stuff, like the argumentation, once you try it, it really is — and the kids do seem to respond well to it. It makes a difference.

Although Lydia acknowledged reluctance on the part of some of her colleagues, she identified a network of colleagues who were “NGSS-minded,” as she described them. Lydia seemed persistent to expose other teachers in her school to the benefits of NGSS-aligned lessons despite their initial resistance. She had facilitated much of the NYSSLS professional development that had taken place in her school district and was optimistic that teachers would be willing to change if given the necessary support and guidance.

At this stage in the adoption of the NYSSLS, it seemed districts had made varying investments in implementing reform. Even in districts that had made some effort to educate teachers on the changes to the standards and the associated shifts in pedagogy, large-scale adoption and student engagement seemed limited by the lack of continuity within districts and between classrooms. The interviewed teachers identified themselves as agents of change in their schools and personal learning networks. The investment in professional development for these Master Teachers was likely to impact many teachers and students beyond the initial participant group.

**Teaching engineering confidence.**

One of the main goals of the workshop series was to increase teacher confidence in engineering instruction through awareness and practice. As earlier research has shown, increased self-efficacy often leads to greater likelihood of implementation in the classroom, particularly with a group of highly motivated teachers (Bandura & Adams, 1977; Gibson & Dembo, 1984; Slagus, 2019). Principally based on the situative perspective model for learning, the workshops allowed teachers to participate in the same engineering tasks intended for their own student audience. It was expected that this immersive learning experience would augment teachers’ pedagogical content knowledge in engineering (Putnam & Borko, 2000). The teachers’ evaluations of the workshop
format were generally positive; they felt the investment of their time in the sessions was worthwhile. Following the workshops, the teachers all had demonstrated a transition in their vision of how the engineering design process could be used in their science courses. Teachers described in detail how they envisioned or experienced changes in their role and the engagement of students in these tasks. In many cases, at the time of the post-workshop interviews, teachers had already incorporated some elements of engineering in their classes as a result of their participation in the workshops.

In post-workshop interviews, teachers were asked about the structure of the workshop and how it affected their professional growth with regard to engineering instruction. Teachers commented on several themes, including the workshop instructors, the format of the activities as representations of the engineering design process, and the interaction between workshop attendees. Additionally, teachers described how they had integrated, or planned to integrate, their workshop experience in their classrooms. Teachers’ responses related to the structure of engineering tasks in the science classroom and the role of classroom participants in engineering activities. The subthemes related to teaching engineering confidence are summarized in Figure 6.

**Figure 6. Theme 3: Teacher engineering confidence.**

**Structure and influence of workshop.**
Prior to the workshops, interviewed teachers expressed their goals for participating. Generally, they hoped to develop their knowledge in engineering and participate in activities that they could bring back to their students. In reflecting on their experiences, the teachers reacted positively to the structure of the workshops. They appreciated the opportunity to engage in engineering activities in a collaborative setting and were inspired to make connections to their course curricula. Some of the interviewed participants felt there should have been more emphasis on practicing the design process in the activities, which should be considered in the planning of future workshops.

**Instructors.**
The planning of both workshop series and the classroom instruction were a collaboration between university faculty representing several different departments. The electrical engineering workshop was organized and facilitated by representatives from the science education, physics, and electrical engineering departments. The biology workshop was cooperatively planned and taught by staff from the biology and science education departments. This was intended to provide a holistic experience for teachers to develop both content knowledge and pedagogical content knowledge in engineering and the relevant science disciplines. It was anticipated that this would increase teachers’ confidence in their ability to teach their students the principles of engineering through science instruction.

The teachers valued the input of different faculty in their experience. Participants felt that the “team” approach to instruction made the experience more engaging and provided richer context for the activities and conversations that took place during the sessions. Following the electrical engineering series, Joseph said, “it was really useful to have these three speakers who were super knowledgeable and with a little bit of different expertise.” The teachers agreed that this structure
was atypical of their other professional development experiences that tended to be facilitated solely by science education faculty or their teaching colleagues. This may explain the lack of emphasis on the NYSSLS engineering practices in the other professional development experiences teachers described prior to the workshops.

Several participants in the electrical engineering workshop commented on the novelty of including an engineering faculty member, Instructor 3, as a facilitator for this teacher professional development experience. The teachers felt he provided a unique perspective that supported the integration of science and engineering content and practices. Of Instructor 3, PS commented,

He was fantastic. And his expertise as well as what else was shared, it was well done. It was really well done. He comes in with like a different experience and exposure to things and knowledge base. But you know, very interested in us as teachers. I think that was very appreciated by teachers who were there.

Other teachers agreed that this presentation was very engaging. They were most impressed with Instructor 3’s ability to describe the science related to the project, in this case the night light, within the context of the engineering problem. The teachers related to the real world applications he brought to the lesson and hoped to emulate that in the experiences they offered students in their own classrooms. The positive feedback related to involving an engineering expert supports the current literature on engineering teacher education (Hardré et al., 2010; Nugent et al., 2010). The biology workshop did not specifically involve an engineering professional and, while teachers did appreciate the input from multiple instructors with different areas of expertise, the biology workshop participants did not discuss as frequently the “real world relevance” of their engineering projects.

**Engineering activities.**

Both the electrical and the biological workshop series were designed to engage teacher participants in content-relevant engineering tasks. By participating in activities that could be used in a secondary science classroom, it was anticipated that teachers would develop confidence in their ability to adapt similar lessons for use in their own science courses. The activities were chosen by the workshop instructors based on several factors including alignment to the NYSSLS, target student audience, and cost. Many of the teachers appreciated the consideration that went into the chosen tasks. Richard specifically discussed how versatile the potato battery and microbial fuel cell projects were in terms of content area and student age level:

We all, regardless of our content area and grade level we taught, we're all there because we wanted to figure something out about engineering. I think what was really good about it is they gave us things you could take it right to the classroom. You could also use these at any grade level. What I liked about it was it wasn't something where I said, "That's nice, but I don't think I'd ever be able to use that". I think I could find a class where I could use everything we were given. I think everything they showed could be applied to all the levels. I think that was one of the unique things about this compared to other workshops I've been to. So this was great because I don't think there's really any restriction to it, as far as anyone not being able to implement some piece of it in their classroom.
Not only did he identify the value of the biological engineering activities, but he also acknowledged that engineering instruction is relevant to all areas and levels of science study. It was apparent that Richard had reflected on his own experience in the workshop and used that to make changes in his own classroom. He also identified specific implementation strategies for the activities used in the workshops in each of his courses, which are discussed later in this chapter.

While not all teachers agreed that the activities were as adaptable as Richard did, all of the teachers were inspired by their involvement in the engineering tasks to consider possible modifications to their existing curricula that would make their course more inclusive of the engineering practices. Most of the teachers agreed that their active participation in the “hands on” engineering tasks during the workshops was necessary in the development of the vision of engineering in their own classroom. By engaging in the tasks intended for students, teachers were able to envision more clearly how the engineering design process could be applied to support the instruction of their science content. Following the electrical engineering workshop Joseph said,

I don't do the level of electronics that they were teaching us in my class, but, when you're doing things like that, you have time to think about “How would I do something in my class differently because of this experience?” And so, even though I can't do those activities, I do think it was a valuable experience for me. It was a valuable time for me.

Although Joseph did not anticipate using the same activities for the workshop in his own course, he used his time at the workshop to reflect on what he could do to augment his physics curriculum. Sophie expressed the same sentiment about her experience working on the microbial fuel cell:

It was a good activity to see. Any of those activities, they're good to see. I just don't think they would be that applicable to my school. I certainly think any time I'm exposed to an activity, it gives me one more – I may not use that exact activity but again, it starts to get your wheels turning about what you could do, so then that made me start to think about alternative energy when we get to human impact for the LE classes. It's one of those things that any time you're exposed to new ideas, and things that you're not comfortable with, because when you're outside of your comfort zone, then you have to think how you would use it. So, I think the workshop definitely has you do all of those kinds of things.

Neither teacher expected to be able to use the exact workshop activities in his/her own classroom but they both had used their experience with engineering-oriented tasks to begin to develop a vision of engineering in their courses. Sophie described the transformative power of being challenged in a unique setting. By engaging in activities outside of her pedagogical awareness, she was able to contextualize the engineering process through reflection of her own teaching practice. Based on these statements, there appears to be a value in engaging teachers in tasks that are not directly content-relevant. Teachers may be more likely to focus on the engineering process rather than the content being taught if the task is not within their own content area of expertise. Teachers who did not find relevance in the activities themselves were more likely to engage in reflection about the engineering process in their own courses.

Teachers were quite appreciative of the unique format of the workshops. Most of the participants had shared experiences in professional development in the past; they described a
lecture-based format with little or no opportunity to engage in the practices being discussed. This workshop was novel in that teachers participated in immersive hands-on laboratory activities to produce their own engineered products which were integrated with direct instruction on engineering. Lydia described her perception of the biological engineering workshops, “The hands-on experience was invaluable, definitely. And I liked how it was paced. I liked that there was an intro. We worked a little bit. There was more content, explanations.” Another teacher commented, “Just the construction, the building, to working with things that I have not done in a while outside of my normal domain, that was fun. It was enjoyable.” Universally, the teachers felt this was an engaging and productive approach to learning engineering. Jack said of the experience,

We did things in the workshop, which was awesome. It wasn’t just someone talking about the engineering process. We were actually soldering and we had a product at the end of it to feel good about. That was much better than a lot of PD experiences.

The opportunity for teachers to practice the activities and skills themselves increased the anticipated likelihood of classroom implementation. Engaging in actual engineering experiences contributed to the development of teachers’ confidence in engineering as well as a positive attitude towards the practices. It was expected that Jack’s pride in his completed projects would increase the likelihood he would share this experience with colleagues and students.

Prior to the workshops, Richard’s inexperience with engineering had prevented him from applying engineering design tasks in his science courses. He lacked an awareness of the engineering process, which contributed to a limited confidence in his ability to create and carry out relevant and appropriate engineering activities in his classroom. He reflected on this after the biology workshop series:

I think if people see and give ideas like this that were simple, which can then be a platform for kids to jump on and you can really take it anywhere you want, I think. Until people see examples of it, I think they're going to still be kind of hesitant.

Richard anticipated that he, and others, would be more apt to implement engineering tasks in the classroom after participating in a workshop that provided specific examples and experiences for teachers with the target practice. This applied also for the technical skills involved in the selected workshop activities. Many of the teachers in the electrical engineering workshops were not experienced in soldering or had not practiced the skill in some time. One teacher commented, “I’ve soldered before but kind of messy and on my own and no one told me what to do. So that was a really positive experience and something that maybe I would use in my classroom.” His experience in the workshops increased his confidence in the soldering task, making him feel capable of employing that skill in his own classroom.

Teachers also felt they gained unique perspective as students in these workshops. One teacher recognized this novel component of the workshops: “I felt going through the labs that students would go through was fantastic.” The activities were framed by a situative perspective to model a typical secondary science classroom partaking in an engineering design challenge. A brief introduction to the problem and necessary content knowledge was provided first, then teachers collaborated in pairs to construct, test, and optimize their products, just as their students might do in an engineering-based lesson. Most of the teachers had very little experience in engineering prior
to the workshops, which was likely to be true of their students, as well. Jack described the value of this format from his perspective:

Looking at it from the point of view that this is something we could be having students do, actually doing it myself, that I think helps showcase places where students are going to falter. You can anticipate what parts of a project are going to be more difficult, which need to be explained more, or what parts you can let them go because it’s going to make sense, it’s not dangerous, things like that.

Providing teachers with a sense of the student learning experience made them more sensitive to their students’ responses to the novelty of the engineering design process. In reflecting on their own experiences, teachers identified some of the potential pitfalls of introducing students to engineering. Jack’s advanced awareness of his students’ needs increased confidence in his own ability to implement the lesson in his class. This was expected to create a more productive and positive experience for him and his students in his classroom.

Teachers also gained insights about their role as instructor while participating in these activities. Prior to the workshops, Lydia had tried several lessons she believed engaged students in informal engineering. She described these tasks as very student-centered with minimal direction from the teacher aside from identifying the initial problem and supplying materials. Following the workshop Lydia considered reframing her engineering lessons in light of what she experienced. She reflected on this:

Well, so actually just manipulating those things; and when it didn't work, I had to go through and try that same thing, try that again. And then really just look at mine and compare it maybe to someone else's or review the steps again. I can also see a student's frustration, though, and that made me very sensitive to being at least available and not constantly saying, "I don't know. You – try to figure it out." Because at some point – you can only do that so many times, I realized. Because even me as a student, I was like, "Yeah, this is the first time I'm doing it, so I could try it a million times and it's not working, I'm just going to throw in the towel."

Many of the teachers intended to consider their experience as an engineering learner in the implementation of engineering tasks in their science classrooms. Experiencing the activities prior to using them in the classroom seemed to increase teachers’ confidence that they could avoid typical pitfalls by anticipating their students’ reactions to the task. They hoped to use this to design lessons that supported student learning and minimized the frustration that students might experience through the iterative design process.

All of the interviewed teachers shared the products of the workshops (the nightlight, home alarm device, and microbial fuel cell) with their colleagues and students. Teachers were excited to share their learning experiences. The teachers described engaging their students in conversations about the science involved in designing the device as well as the optimization process. With their colleagues, teachers discussed classroom implementation and the NYSSLS engineering standards. All of the teachers, like Joseph, were very appreciative of the “take away materials” they received during the workshop:
It was nice to walk away with something. Sometimes, you go to professional developments and you walk away with a set of notes or a PowerPoint, but, here, we walked away with something – even though they were something most teachers probably wouldn't use directly in their classroom, putting it in the classroom had students say, “Hey, what's that?” and they start talking about that, you know? And so I know it cost the program a little bit of money, but I think it was worth it because those conversations you have with students outside of the curriculum, in between your classes – those are very important.

As Joseph did point out, there was an expense to the workshop sponsors associated with providing materials for each teacher to take home but the return was significant as teacher participants were able to influence others by sharing their engineered products. The informal teaching moments that Joseph was able to share with his students by displaying the nightlight and home alarm system in his classroom provided an opportunity to converse with students about content that was not directly part of his curriculum as well as the engineering process and engineering careers. These shared experiences with colleagues and students can facilitate immediate dissemination of knowledge as participants were able to bring their products back to school the day after the workshop.

Engineering design process.

A central element of the workshops included projects meant to engage teachers in the engineering design process. Each activity was framed as a practical problem to which teachers were challenged to devise a solution. As most of the teachers had little or no experience with engineering, these tasks were meant to develop participants’ familiarity and confidence with the design process. For Pedro, the workshop series accomplished that objective. He said, “It made, I think, greater awareness of the process itself, and less taken for granted in some aspects. I was not – it's not my area of expertise.” Jack, who began the workshops with the greatest sense of engineering awareness, felt the activities provided a strong foundation for others who were new to teaching engineering:

I think for someone who hasn't had any experience, I think some introduction to that process is good, the idea that we evaluate things and make changes is a good thing. We followed a design that was given to us but then we were encouraged to evaluate it ourselves and make some decisions about how to improve it. So that’s kind of like maybe the prototyping process, sort of the “iterative-ness” of the design process. So there were elements of that included, which was nice.

Most of the teacher participants entered the workshops with a rudimentary understanding of engineering and a limited awareness of the design process. The workshop presentations and activities supported the development of knowledge in these areas, thereby influencing how the teachers applied engineering in their science courses. Lydia admitted to having limited understanding of the engineering design process prior to the workshops. In reflecting on her experience she recognized that the lessons she had previously categorized as engineering lacked the iterative optimization process. She said, “I like that idea of being able to assess what went wrong with the system and being able to make those corrections. That is exactly what I brought back to the classroom, as well.” Her experience in the workshop had already influenced her to make changes to her pedagogical approach to engineering instruction.
The microbial fuel cell, one of the projects used in the biological engineering workshop, was presented in the context of a discussion about human dependence on fossil fuels. Participants were challenged to engineer the most productive fuel cell by testing variables associated with the soil and environment and collaborating to share the results of each group’s experiments. In evaluating the fuel cell activity specifically, Richard captured the intended essence of the task:

I think setting up the whole thing with the fuel cell and seeing how [the instructor] presented it. He gave us a context at first. He told a little story in the beginning. Then he presented us with all the variables and the options. We jumped up, jumped in, and I could see kids doing that. I felt like, "Okay, if you have everything set up beforehand and you give them the options, they'll go set it up, try different things, and then again, if they don't get the success or the results they expected, you can go back and say 'All right, let's retool. Let's figure out how you maximize it.'" Even if they do get good results, it's how can they -- how do you take the results you have now? Let's try to improve upon it. I think, what I've learned is that even if you have success or don't have success, everybody still needs to maximize what they've done. How can you improve it? It's not like, "Okay, we did it. It's done." It's "Okay, we did it. Now how do you make it better? How do you improve upon it? How can we scale it up?" That was one of the things Dan was talking about. How do you scale this up like we do? I never really thought about that in bio. It never really occurred to us in our curriculum, but you could take the success and say, "Okay, now you've got that." It's almost like a business model. Now you've got this, now how do you improve upon it?

Richard spoke confidently about what he took from the activity. He demonstrated a clear understanding of the engineering design process and he made the connection between his course content and the fuel cell activity. He recognized that students would be able to use their knowledge about microbes and their environment to manipulate system variables to maximize energy output. He identified how this activity could be used in his classroom but also considered the broader applications of the engineering design protocol. Richard acknowledged the value of optimization in these types of student activities whether the results of testing were perceived as success or failure. In the fuel cell project, the concept of “scaling up” was emphasized which clearly had an impact on Richard’s perception of the engineering design process, as he described how he would use the same model to motivate his students to optimize their design solutions. Richard made specific connections to his own students and curriculum, suggesting his intentions to follow through with implementing engineering instruction in his classroom.

Despite the growth in engineering knowledge and confidence that teachers did experience, continuing gaps in understanding were identified in post-workshop interviews. Based on their responses to questioning following the workshops, it was apparent that teachers still wavered in their confidence about the design process, particularly related to optimization. Some of the teachers felt the format of the activities restricted the optimization process with limited variables to manipulate in the design, making the projects feel “a little bit like a cookbook lab,” “very guided,” and “very rules-driven.” Several of the teachers commented that they were unsure of what the optimization component of the activity was. Jack said of the electrical engineering projects,
We didn't have much control over what we were doing. It was neat that we were able to change the color I think by tweaking RGB so that was kind of cool and that related to the science lesson. But the control that we had over the project seemed very minimal. Again, I don't know how we could do something so technically rigorous and also be able to tweak it.

The recognition of this limitation is positive, in that it demonstrates that teachers have sufficient awareness of the engineering process to identify its iterative nature. Some teachers seemed disappointed that the optimization phase of design was not emphasized in the activities. One teacher was hoping for the opportunity for optimization: “So what I was expecting was that, after we had built something, then we'd have to try to optimize it in some way and we'd come back with – redesign it, and I feel like we didn't get the chance to do that.” Based on their reflections following the workshops, it seemed that teachers were still struggling with how to incorporate this element of the design process into their own engineering lessons. Joseph said about the workshop activities, “I don't know how they could have altered it and had gotten that task done because it was a lot of new material that they had six hours to get us to learn.” Time was likely to be a limitation in the teachers’ classrooms as well. Providing additional support to teachers in designing engineering tasks that allow for more concrete examples of optimization should be considered in planning future workshops.

**Career exploration.**
Increasing teachers’ awareness of career opportunities and educational pathways in engineering was another objective of both workshops. In the electrical engineering workshop, a significant portion of the last evening was spent discussing engineering majors offered at the hosting university and advising science teachers on how to support their middle and high school students’ pursuit of these pathways. Teachers received classroom-ready posters about the university’s majors in engineering (see, for example, Stony Brook University Institute for STEM Education, 2019a) during this session. In the biological engineering workshop, specific career connections to the microbial fuel cell activity were discussed but the discussion was abbreviated due to time constraints (the biology workshop ran for two sessions while the electrical engineering workshop was a three-session series). Teachers valued this aspect of both workshop series, as many were initially motivated to incorporate engineering instruction in their courses specifically to provide knowledge of career paths in the field to their students. For Jack, this was the highlight of the sessions: “I think the best thing I got out of it was a little bit more information and discussion of engineering as a field of study and a career field.” Another teacher explained that the workshops “helped me start to think about engineers.” The conversation about engineering majors and careers allowed the teachers to make more concrete connections to engineering as a field of study and profession, not only the engineering design process. A more detailed discussion of this component of the workshops follows later in this chapter.

**Collaboration with colleagues.**
Science and engineering are both collaborative in nature. The format of the activities and the organization of the classrooms where both workshops were taught facilitated interaction between teachers. For example, in the electrical engineering lab classroom, soldering stations were shared between two adjacent teachers. The microbial fuel cell activity was designed for teachers to work in pairs to test the energy output of fuel cells under contrasting conditions (i.e., hot vs. cold
incubation, acidic vs. alkaline soil). Teachers agreed the collaborative structure of the workshop activities positively impacted their learning. Lydia found that working with a partner made it easier to resolve some of the obstacles she encountered during the electrical engineering projects: “It was just good working with someone else to know that we could do things step-by-step and I would watch him and he would watch me. It would have been much harder if I was doing it alone.”

The teachers personally experienced more engagement in the tasks as a result of the social interaction with their activity partner. One teacher said that working with a new friend made the activities “a lot more fun and a lot more interesting.” Another teacher said of the discourse between partners: “it's good because it lets you come up with different ideas.” Input from multiple individuals further supports the creativity needed to solve problems through engineering.

Jack described another benefit of the collaboration with his partner – informal self-assessment:

You have to understand it pretty well to explain it to somebody else or I think there was one or two times where I thought I understood something well and then I was talking to [my partner] about it and I realized, oh, I’m wrong or I can’t explain this so I must not get it that well.

This teacher was able to identify his own misunderstandings as he discussed the design plan with his partner. By identifying some of his own weaknesses in the workshop setting, this teacher was less likely to make those same mistakes when presenting this lesson in his classroom. Most teachers planned to emulate this same collaborative structure in their own classroom engineering activities. Richard highlighted the importance of fostering communication during student activities:

I think collaborating is a major thing in science. Kids think scientists work by themselves, and they don't. It's a team approach. I think it's good for kids to see that. We all work in large groups when we're actually doing our science work.

Collaboration was an important feature in the format of these activities as it challenged an oft-held misconception that scientists work in isolation. The teachers recognized the value of collaboration in their own learning experience and expressed a desire to create the same atmosphere in their own classrooms.

Both the biological and the electrical engineering workshops were designed to provide an introductory exposure to engineering and the design process for science teachers through a relatively brief professional development experience. Teachers felt the novel interdisciplinary approach to instruction provided relevance for the inclusion of engineering within their science curricula by demonstrating the cohesion between the disciplines. The opportunity to engage in classroom-ready engineering activities was engaging for teachers and offered a demonstration of the engineering practices with which teachers were unfamiliar. Participants were inspired by the tasks to consider revisions to their existing curriculum using the workshop activities as a model for other lessons. Teachers expected that by participating in the activities from the student perspective they would be more prepared to anticipate the needs of their students in the classroom as they introduce these novel engineering-aligned activities. Teachers were very appreciative of the engineering careers conversation and all anticipated continuing that discussion with their students. The opportunity to interact with other teachers through the engineering design process in the role of the student provided teachers with insights that developed their confidence and
pedagogical content knowledge in engineering. Based on this, it was expected that teachers would follow through with classroom implementation.

**Implementation in science courses.**
With the primary goal of teacher professional development as the ability to affect change in classroom instruction, an evaluation of teachers’ plans to implement the principles of the workshops in their science courses was essential. Teachers were asked to describe their vision of an engineering activity in their science class during both pre- and post-workshop interviews. Transitions in five key domains of instruction were identified: 1) integration of engineering tasks with science content, 2) scope and scale of engineering tasks, 3) objective of engineering tasks, 4) science teacher role in engineering tasks, and 5) student engagement.

**Integration of engineering tasks with science content.**
The NYSSLS intends for the engineering practices to be infused into science courses to support and complement science instruction while contributing to the development of students’ problem solving and critical thinking skills (NYSED, 2016). The introduction of engineering in the science standards was entirely novel in New York State and required a significant shift in teachers’ approaches in the classroom. Prior to the workshops, teacher participants struggled to find relevant ways to integrate engineering into their course curricula. After participating in the workshops, most teachers were able to provide a rich description of how they intended to utilize the engineering practices in their courses to facilitate science learning. In some cases, teachers had already made changes to their teaching practice as a result of their participation in the workshops.

In pre-workshop interviews, while Pedro demonstrated an understanding of some of the basic principles of engineering instruction, he was unable to describe a complete lesson for his Earth science course or provide a specific unit of instruction that would lend itself to an engineering design task:

> There are a few lab activities where we can offer some application but it’s very - almost done to insert a little bit of engineering; it’s not inherent in the course the way it’s structured from this date… I definitely see the potential and I can see it happening and would think they would be a different type of lesson and learning experience, like I said, I don’t want to say just authentic a lot, but it actually is the application of it. It’s not knowledge for knowledge sake; it’s knowledge to apply to solve a problem, and that’s really what we’re moving towards with these new standards.

Pedro was clearly motivated to make shifts in his teaching practice based on the value he attributed to engineering but he struggling to find meaningful connections between his science content and the engineering practices. He suggested he was making connections to engineering in his course but his definition of engineering was limited as he focused solely on problem solving and knowledge application with no reference to the design process.

Following the electrical engineering workshop series, this same teacher provided details of a very specific lesson he had taught that engaged students in an engineering task to apply the science knowledge acquired in his course:
In Earth Science, the course I teach, we have some engineering designs when it comes to the topic I’m currently teaching, dynamic crust, with the designing of structures. And we’ve made - engineered buildings on an earthquake shake table where we had it shake and used gummies or marshmallows and pasta, or popsicle sticks, or other sorts to make a structure and then vibrate to see how it would respond to that... in Earth it would be more like design of structures in the event of a potential disaster, catastrophe. Greatest length of time that it was standing in height was the formula we put it through. And the scenario was like the Oregon coastline, a school on the Oregon coast where it is prone to earthquakes and tsunamis, massive ones on a less frequent scale. They had to build it.

In the post-workshop interview, Pedro was able to describe in great detail a sample engineering lesson that aligned with a standard unit of instruction in his Earth science course. The task he described here made use of the complete engineering design process to apply science knowledge to resolve a real world problem. Initially Pedro described engineering as “not inherent” in his course, but following the workshops he demonstrated a discrete connection between science content and engineering instruction.

Although Jack had experience teaching an engineering elective, he also found it difficult to use engineering in his physics course purposefully. Prior to the workshops he described how he was using what he considered to be engineering in his physics course:

I like to do – well, what I call like engineering activities like the day before vacations, little engineering challenge, making paper towers or spaghetti bridges, you know, so not a real formal introduction to any sort of engineering. But, you know, giving the kids a chance to do something hands on and you know, maybe sort of apply some of the physics that we’ve learned to something practical.

He admitted these activities did not specifically connect to the NYSSLS engineering practices and were presented tangentially to the physics course content. Rather than use the engineering practices to support his science instruction, Jack was treating engineering as a separate unit of instruction. His statement also implied a devaluation of engineering. By doing these activities specifically on days preceding vacations when students tend to be distracted, classes were often disrupted, and attendance may have been low, this teacher had suggested that engineering was not necessarily something worth spending productive class time doing.

After the workshops Jack presented a very different perspective on how he envisioned integrating engineering:

I would want it to be something that isn’t a standalone project. I don’t want them to think that engineering is separate from science. I don’t want to learn science and then do engineering and then go back to learning science. It would be really cool to incorporate some of the learning of physics in the project itself.

He continued with details of very specific plans for embedding the engineering practices in his course to facilitate the construction of science knowledge:
That’s kind of what I was thinking about, incorporating the physics into the engineering project. So if my kids this year did an inquiry lab where they discovered Newton’s second law, if they're already going to do that anyway, that can be embedded in an engineering project, which could help even focus them about why they're doing the experiment that they're doing. That might be a way to save some time, kill two birds with one stone, do some of the physics activities that we would normally do in the mindset of we’re trying to solve this problem. If a whole unit is framed in this engineering project, we can accomplish – maybe, I don't know – maybe we can accomplish both things at the same time.

In his reflection following the workshops, Jack asserted that science and engineering instruction should complement each other, rather than be emphasized exclusively as he described before the workshops. He anticipated that his students would benefit from utilizing their science content knowledge in the context of solving an engineering problem. He considered making seemingly simple revisions to include elements of engineering design in a preexisting activity on a specific physics concept. By minimizing planning and carrying out engineering activities in class, it was expected that Jack was likely to follow through with implementation. His statements demonstrated a shift in his thinking of both the value and place for engineering in his science course. Following the workshops, Jack described the complementary combination of engineering and science as it was intended in the NYSSLS.

With regard to inserting engineering into her science course, Lydia showed a noteworthy change in perspective as a result of her participation in the electrical engineering workshop series. Before the workshops, she said about the engineering design process, “I think that doesn’t fit all that well right now into my curriculum.” She was able to describe some lessons she loosely identified as engineering-aligned but was not confident in her ability to provide instruction to support the engineering standards. For example, she identified a potential application for engineering within the human body systems unit:

In the body systems we could certainly do, kind of like with the dialysis. You could do that for – you could do the ventricular pumps and – you know what I mean? There's different places in the body systems you could. I guess I've never even thought we could even look at a ventilator… I think with any body system, if you look at the problems with things that happen to the body systems, you could certainly look at biological engineering.

She was able here to describe engineering in terms of problem solving but provided no detail regarding identifying constraints and limitations or optimization in this project. Additionally, her references to biology content were generalized and related to concepts that were not central to the existing New York State biology course. Even before the workshops, Lydia was highly motivated to provide opportunities to engage her students in engineering. In the follow up interview, Lydia described a detailed and content-specific lesson she had devised and already employed in her classroom using what she learned during the workshops.

I had them look at a graph about the temperature of Iceland. And I'm like, "But look. I just bought these tomatoes from there." So we – they had to figure out how to design a greenhouse and what factors needed to be regulated. So eventually – it
took them a while, but – one student thought of, "You would need a huge magnifying glass," which I guess could be – I was trying to be very supportive. I was like, "Well, maybe we could put magnifying glasses on the roof." So finally, they came up the idea of a greenhouse and then the idea of pumping in CO$_2$ and regulating the CO$_2$ levels for photosynthesis. So that was all good, and then keeping the temperature. So we did that when I was going through photosynthesis. So now, I'm starting to incorporate a lot of those engineering concepts more so, or at least be aware of where I could work it in.

The lessons she described after the workshops demonstrated a much stronger connection between the relevant science content being taught in her course and her students’ engagement in the engineering practices. Her second description provided details of a specific activity associated with a discrete unit of biology instruction, which was lacking in her pre-workshop response. She had applied the knowledge gained from her experience in the workshop to design a lesson that required her students to develop a solution to a specific real-world problem within constraints using their knowledge of plants and photosynthesis.

Each of these three teachers made progress in terms of their understanding of the engineering design process as well as their perception of the relevance of engineering in their science course curriculum. Prior to participating in these workshops, the teachers acknowledged having very little training in the NYSSLS engineering standards. This was reflected in their inability to describe appropriate and meaningful engineering tasks that supported their science instruction. In their post-workshop reflections, teachers made distinct connections between their science content and the engineering design process. It was apparent that their involvement in the activities during the workshops provided the foundation and inspiration for infusing elements of engineering into their courses in a meaningful way.

Scope and scale of engineering tasks.

Many of the teachers, prior to the workshops, were overwhelmed by the idea of including engineering in their already rigorous science courses. Based on their preconceived misconceptions, these teachers initially described engineering tasks as technology-dependent and time consuming. In post-workshop interviews they considered more manageable means of engaging students in the engineering practices within their existing science curricula rather than creating long-term tangential units of instruction to address the engineering standards.

Richard, in particular, demonstrated growth in this area. Before the workshops he felt limited in his ability to include engineering in his biology course, in part, due to his perception that engineering lessons must be long-term, multifaceted projects that incorporate advanced technology. He described one such activity in the pre-workshop interview:

And one of the things we've been doing is, we've been involved with water quality testing and all that with rivers because we are in the watershed for [a local river]. So we know that the water quality is. We know that it's a result of what's going on in the environment. So what can we do to fix that? To solve that? But of course, right now, I don't have the resources for that at the moment. But in theory, if pie-in-the-sky, if I could do it all, I would definitely have my kids work on that for a long period of time.
While this idea could potentially engage students in the engineering design process, it was a large-scale task that would be difficult to implement in a standardized course curriculum with limited time and financial resources. When asked about the relevance of engineering in his biology course, Richard also made mention of modern biotechnology innovations like gene editing. He acknowledged that these were topics he had discussed in class but “we haven’t done anything in lab-wise I would say that’s hands-on lab oriented engineering activities.” Before the workshops, this teacher demonstrated a misconception that engineering and technology were the same; he failed to recognize that engineering is a process that leads to innovation.

Following his participation in the biology workshops, Richard focused on more practicable engineering elements that could easily be infused into the core course activities he was already doing. Instead of creating entirely new technology-dependent units of instruction to accomplish engineering, Richard intended to make modifications to the format and objectives of labs and other activities he was already using:

Just looking at some of the preexisting labs I do already and seeing how they can apply engineering to that. I haven't really given deep thought into it, but just off the top of my mind, I think the cellular respiration lab. I think there's engineering components in that. There's even with the diffusion through the membrane lab, I think there's something engineering wise with that. Whether it's coming up with different ways to develop a semi-permeable, something like a filtration system, or osmosis or something. I'm just throwing ideas out right now off the top of my head. I think those areas can be areas where we can simplify certain things, and have them try to engineer something different, try new experimental designs. So I think those lend themselves to it.

He had modified his perceptions by the post-workshop interview. This response focused more on the process of engineering rather than the technology that is innovated as a product of engineering. Additionally, he more readily identified common high school biology content that he would use to engage students in the engineering process rather than develop completely new units of instruction that would be challenging to implement in the classroom due to time and resource limitations. He also acknowledged that these activities would need to be thoughtfully scaffolded as students begin to develop familiarity with the engineering process:

I think I have to come up with small, quick, introductory ways of building their confidence in it, and getting them to understand this is the direction we're moving in. So I don't think I could do something big with them right off the bat, but I think they need to be – get their feet wet a little bit, and get comfortable with it.

Following the workshops, Richard recognized that the scope and scale of engineering activities did not need to be overwhelming for either the teacher or the students. As he stated here, small, manageable tasks could be used throughout the curriculum of any science course to expose students to components of the design process. The perspective gained during the workshops suggested this teacher would be more likely to implement engineering practices in his science classroom after the workshops.

Objectives of engineering tasks.
Prior to the adoption of the NYSSLS, most New York State science courses were typically content driven. The previous standards document enumerated student expectations as knowledge developed through participation in the course and demonstrated on the end of year exam (NYSED, 1996). The newest state standards had shifted the instructional focus from pure content knowledge to application of knowledge through the development of science skills. The NYSSLS identified specific student learning objectives based on using science knowledge to accomplish one or more of the science and engineering practices (NYSED, 2016b). So extreme was this transition that some teachers found it difficult to describe an engineering-aligned lesson prior to their participation in the workshop. In the initial interviews, several teachers identified a building or modeling activity when asked about how they were using engineering in their course. These tasks required students to demonstrate their science knowledge through the construction of some system or object with little or no emphasis on engagement in the practices of engineering. Very few teachers considered the engineering design process in their pre-workshop responses. Following the workshop, teachers’ lessons focused much more on the application of science knowledge through the process of engineering design, placing less emphasis on the product itself.

Joseph progressed in his thinking about the objective of engineering tasks during the workshop. Prior to the workshops, Joseph struggled to identify a lesson that enabled students to practice engineering. He mentioned a few projects he had used in the past but admitted that engineering was lacking in his course:

“They do builds, like a roller coaster ride or a carnival ride as a project. There was a tower building contest at the beginning of the year. We used to have them build boats and then we actually go to the pool and they're cardboard boats and they just get in them and paddle around. But yeah, we're limited. It's unfortunate.”

This teacher failed to provide any detail of how students employed the engineering practices while completing these tasks. All of the assignments he described here focused on the product students created, rather than the process students were actively engaged in while designing their roller coaster or boat. Additionally, the examples offered by this teacher were representative of stereotypical engineering pathways based on limited awareness of the array of possible engineering applications. Following the workshop series, Joseph was able to describe, in detail, a very specific lesson he had developed as a direct result of his involvement in the electrical engineering workshop:

“I was thinking about, in my mechanics unit, when we do projectile motion, I have them predict where a projectile will land and then launch it and see if it does. But maybe I can have them build something where they can alter the distance it goes and then I’ll give them the distance I want it to go and see if they can calibrate it to that distance.”

He described here an activity that would engage students in the optimization process. In this task, he identified constraints for students to work within and required them to modify their device through the engineering process to satisfy a specific target. He began here to identify engineering more as an action rather than an object. By placing more emphasis on the process rather than the final product of the activity, students would be engaging in the engineering practices and developing the engineering skills that are enumerated in the NYSSLS.
In pre-workshop interviews, many of the teachers described the construction of some tangible product as the objective of their engineering activities. For example, Lydia discussed an assignment in which she had engaged her eighth-grade biology students:

I just started last year and I’m doing – and it didn’t work out so great last year, but I realized is to have them – have them design that, how would you make a model cell. So, how would you show that one thing can diffuse and other things can’t? So I feel like when I have them make something that works, even though it’s not solving a problem, they have to plan and design and make a plan and then – and then figure out the parts that they need and put it together. It’s not really a problem, so to speak, that they’re solving, but it is making something. The honors group does a human body project where they have to take supplies and make a working model of the human body. So the lungs we do together in class and then they have to do like the excretory system, they choose another system and then they do that.

The tasks Lydia identified described modeling, an important science practice, but failed to connect the activities to the engineering design process effectively. The emphasis of the activity was the cell or body system model itself, rather than the process by which students designed, evaluated, and modified their model. The ability of teachers to engage students in authentic engineering tasks was restricted by this type of misrepresentation. Following the workshop, the same teacher described the changes she had made in her classroom to accommodate the incorporation of more engineering design practice:

At first, I thought my role should be like, "Here are all the supplies you'll ever need – here are the supplies. Do something with it," which is how I used to do – like, "Make a lung model. Here are the supplies. Do it." But then I’ve been like, "I don't know. What would be – if you had your choice of any supplies, what would you want? What – make a wish list or what would you – your dream-come-true of supplies." So I left it a lot more open-ended.

Lydia demonstrated her change of perspective here. Through her participation in the workshop series she was able to recognize that her previously identified engineering activities were lacking in terms of student engagement. She reflected on this and considered revisions to her lessons to provide students with more opportunity to make and test their design choices.

Lydia was eager to implement these changes in her course. She described an experience that she had in her classroom after the workshop:

I was more accepting of them, asking them what their end goal was, and then having them think through which would be the better material. Because a lot of times, they'd want to use clay for everything. And I'm like, "Well, do you want to stand it up? Let's think what the final project's supposed to look like." So I kind of incorporated that idea, like, "What is the endgame and how are we going to get there," just like we did when [Instructor 2] introduced, "We want the – " the nightlight, "We want it – we want it to function as a nightlight" kind of thing, so, "How are we going to get from the – what our – what our product is supposed to be?" to "How we going to get there along the way?"
Her language demonstrated a shift towards a more process-based and solutions-oriented engineering lesson. In her post-workshop lessons, Lydia provided her students with more ownership in making design decisions. Rather than prescribing materials and a specific end goal, she proposed a problem for students to solve using creativity as well as their science knowledge. By engaging in the activities during the workshop, Lydia developed her awareness of the engineering process as well as gained pedagogical content knowledge. She had developed a more explicit vision of engineering in her classroom for both her role and that of her students and gained confidence in her ability to structure these engineering activities for her students. She used her experience in the workshop to recognize where her previous lessons were deficient and made adjustments to align her instruction with the engineering standards.

Sophie, another biology teacher, demonstrated a similar progression in her approach to engineering. In her biology course, Sophie was already engaging students in some level of engineering instruction but her assignments also tended to emphasize the product of a build rather than the process of engineering. When asked before the workshops about how she employed engineering in her course, she identified a lesson in which students built a filtration device using supplies she distributed:

I do kind of a filtering thing where we – I give them some articles, we read about dialysis equipment, and then I have them build their own filters. I put out materials and basically don’t give them anything other than - I just take a water bottle upside down in a beaker. And then I put out fiberfill and cotton and coffee filters. And I have water contaminated with different levels of things, different thicknesses. I give them a sheet that’s got different models of that blank and then I ask them to just start with their baseline, run it through, see how it goes, and then that’s what engineers do. They look at the problems. And then once you see if your problem is to filter the water to make it clear, see how that worked, see what works, see what filtered out, what didn’t, and then keep modifying. And since they have - because of time, they have kind of four models to do, and then I eventually tell them that they have to finalize their model and then tell us. And they kind of compete to see who did the better job sort of thing when they do that.

While she did explain that her students were required to perform four iterations of their model, the main element of assessment in the lesson was the filtration device itself, not the process by which the device was developed. In this lesson she provided very restrictive directions for the task by identifying the problem and providing specific materials for the students, limiting the opportunity for them to develop creative solutions to the problem. In the post-workshop interview she recognized this and described how her perspective had changed:

I was thinking of – but I think more open ended with a general task or a general objective, and then maybe not give them too many rules, and try to have them do the whole prototype it, see how it works, back to the drawing board kind of thing.

Here she described the framework for a task that emphasized the engineering practices more than the science practices, unlike the lesson she had detailed before the workshops. Additionally she attributed a value to providing students with more flexibility in the design of their solutions.
In both the pre- and post-workshop interviews, Sophie expressed concern about her students’ ability to accomplish engineering tasks with very limited background in the domain. Because her district did not have an articulated K-12 program, she worried that students would not have been exposed to engineering prior to high school. Following the workshop, Sophie had considered an alternative approach to how she might introduce the concept of engineering through her instruction of biology, without limiting the ability of students to experience the design process. She had considered a unique means of approaching the topic through “reverse engineering.” She identified several content elements in which she had considered attempting this, for example:

I was even thinking, and I've never even thought of this before, but I was like, "We could even get kids to do things like reverse engineer a plant." Figure out what does the plant need? How is it going to get the plant? Can you tell how the plant is doing this? Why does this plant work better in the desert than this plant works? Not that that's necessarily engineering, but it might get – start to get them to think at a more concrete level. Again, down the road, obviously if they're doing things like that kind of engineering in nursery school and kindergarten and first and second grade, then by the time they get to us, then a more sophisticated engineering task wouldn't be such a big deal.

Sophie provided an example of the development of her pedagogical content knowledge in engineering following the biology workshops. Recognizing her students’ limitations, she considered an alternative means of introducing the concept of engineering so that they would be more prepared to engage in the design process themselves as they progressed through her biology course. She hoped that by helping her students work backwards through the engineering process early in the school year, they would become more familiar with the practices, providing a foundation for other lessons throughout the year.

The shift from product-oriented to process-oriented tasks was an important adjustment for teachers to make as they began to incorporate engineering in their science courses, as many teachers were likely to hold this misconception of engineering instruction. If teachers failed to recognize the value of the iterative nature of engineering in their presentation of engineering tasks, students were unlikely to meet the engineering standards identified in the NYSSLS. Teacher workshop participants showed evidence of developing their capacity to plan appropriate engineering-aligned lessons and gained confidence in their ability to teach the engineering practices as part of their science courses following the workshop series.

Science teacher role in engineering tasks.
To accomplish the student learning objectives of the NYSSLS, there must be a change in the role of the classroom teacher. Engaging students in the practices of science and engineering often requires open-ended activities with fewer restrictions than the typical science laboratory exercises. NYSSLS-aligned engineering lessons should be designed to allow students opportunities to apply science knowledge while engaging in the design process to accomplish a goal (NRC, 2012). During their participation in the workshops, teachers were able to reevaluate their role in facilitating classroom activities to enable students to experience science and engineering themselves.

At the time of the post-workshop interview, Richard had not had the opportunity to implement engineering in his course, but he had put thought into what he anticipated a re-envisioned lesson
might look like and how it would compare to a more traditional science activity. Richard described his change in thinking at the conclusion of the workshops:

I think I have to be able to let the kids go with certain things and say, "Okay, you have that idea? Try it," rather than saying "No, that won't work" or just demonstrating something and saying, "Do this and replicate it." We have to be able to let go. As science teachers, we always like to have control. I think we have to be able to let the kids go and think a little more freely and say, "Try that and see what happens. Go back to it." Rather than saying, "Here's how it works. Let me demonstrate it. Now you repeat it. Rinse, wash, repeat."

Richard expected to transition from what he called the “sage on the stage” to the “guide on the side” as he looked forward to embracing a more NYSSLS-aligned curriculum in his biology course. In his traditional role, Richard described leading students in teacher-directed activities to demonstrate established science principles. He envisioned a different model when his students engaged in engineering lessons. He expected to make his lessons more student-centered by providing more opportunities for knowledge application through the design process. Richard recognized that to properly incorporate engineering in his science classroom, he would have to make changes in many aspects of his teaching:

Once they understand, and also they need to know that in the end, their grade is not contingent upon a success or not. It's contingent upon their design and how much they were able to discuss among each other. I think I have to think of different ways of grading too, assessing the group work. I might not be able to see everybody's work that's – at the conclusion of it, but I definitely would need to be able to walk around and see that – who's engaged, who's not engaged, where the ideas are coming from. Maybe almost in the beginning, set up roles for people to have so we have different roles for people, but they definitely need some kind of structure in the beginning, I think, so they know what's expected and they know where we're going with it. Otherwise, I think if I just jump in it blindly with them, I'm going to lose a lot of kids.

Richard had considered the implications of adding elements of engineering design in his classroom. He recognized that he must develop lessons that provide structure for students who are likely to have had little past exposure to the engineering design process. He had also reflected on the collaborative nature of the design process and demonstrated his intentions of adapting lessons to allow students to work cooperatively with support from the instructor. The considerable amount of thought Richard had committed to integrating engineering suggested he was likely to follow through with implementation with anticipated success.

Lydia experienced a similar transition in her vision of engineering in the classroom. Prior to the workshops she had described several activities she had been doing which she considered to be at least somewhat engineering in nature. At the time of the second interview, she had already attempted to implement her revised engineering model in her biology course. Following the workshops she reflected on the change in her place in the classroom:
That body systems project, I was always more involved in the design and then the production of those. And then this time, I just kind of supervised and walked around. And I said – they were like, “Wait, should be use this?” and I go, “I don’t know, maybe. Try it.” I thought it was much better that they were trying, in fact, it was the first year where they tried something and discarded it and tried all over again. Instead of asking me to just help them correct their original model, they – I can’t tell you how many time several groups were just like, “Yeah, can we start all over again?” I said, “Yeah, absolutely.” So I thought that was great.

Like Richard, Lydia expected to provide students with more opportunities to make decisions in the design process. Before the workshops she had described activities that effectively engaged students in modeling and but were lacking in the iterative optimization process. By modifying some of her existing lessons, she offered students more opportunities to exercise problem solving. Both teachers had accepted that the dynamic in their classrooms would need to change for these engineering activities to be successful. Richard and Lydia planned to relinquish some of their control in the classroom to allow students to take more ownership of the learning process through engineering design.

**Student engagement.**

As teachers adjusted their own position in the classroom in engineering-based tasks, it was expected that the student role would progress, as well. Teachers must consider this change in dynamics as they implement a NYSSLS-aligned curriculum in their classroom (NRC, 2012). Many of the teachers used their experience in the student role during the workshop to anticipate the response of their own students to these types of tasks in their classrooms. Teachers expected students to have mixed feelings about the addition of the engineering practices in the science curriculum. After the workshops, participants felt more prepared to assist students to progress past their initial reluctance concerning more open-ended, student-centered engineering tasks.

In both pre- and post-workshop interviews, teachers expressed concerns that students would initially have reservations about the engineering design process. Engineering instruction leverages a unique skill set that most students had not had experience practicing. Teachers acknowledged that they had previously provided few opportunities for students to engage in similar tasks leading most to anticipate that students would be uncomfortable or intimidated by the open-ended nature of engineering activities. Before the workshop, Lydia described her students’ reactions to the engineering tasks she had previously introduced, “It's just such a long learning curve because they are not used to doing that. I know that they have to start somewhere but there's a lot of resistance on the students' end of it, even on a small scale.” Lydia struggled to motivate her students to participate in problem-solving tasks because of their lack of familiarity with the process of engineering. Richard also anticipated that his students might initially be “frustrated” because he would be challenging them in a novel experience.

Following the workshops, teachers were able to more precisely articulate their concerns about student engagement in engineering tasks. Many teachers predicted that students would struggle the most with the iterative nature of the engineering design process. In particular, they worried students would have difficulty accepting failure as a necessary part of the process of innovating. One teacher said, “some of the high-level kids are intimidated by it because they don't like to be wrong.” Richard anticipated his students would struggle initially with their own imperfection as well: “I think it might look messy in the beginning. Anything new is always going to be messy but
that's science. There's going to be failure. I think they have to learn how to fail. That's okay. Safe failure.” The teachers were concerned that students would be uncomfortable with their failures, initially, but anticipated that this would resolve itself as students gained more experience with the design process. With knowledge of this potential obstacle, teachers would be able to plan their engineering lessons to provide support for students as they developed the necessary skills for engineering. Most of the teachers were hopeful that this would be less of an issue over time as students were increasingly exposed to NYSSLS-aligned curricula in their K-12 studies.

It is critical that teachers recognize the potential for students to react adversely to the structure of engineering activities. By participating in classroom-ready engineering activities during the workshops, teachers gained perspective on the student experience. With the awareness of student anxieties regarding failure, teachers can plan accordingly by clearly defining expectations and assessment measures for students at the start of the activity (English & Kitsantas, 2013). Prior to the workshops, Joseph shared his concerns about student reception of an engineering design lesson in his science class:

The students who are motivated by grades are going to wonder for a while, “Why am I spending my time on this?” and, “Maybe I can get the other kid to build it for me,” and maybe even nervous if they know that this will be graded and they're not quite sure how it's going to be graded and, “How am I going to get my 99?” You know, a different rubric than they're used to. It probably would – it would be met with anxiety.

Although he had not yet included engineering in his science class, this teacher was also teaching an engineering elective. He expected to use his experience with this other course, along with what he gained from the electrical engineering workshop series, to inform the design and assessment of the engineering lessons in his physics class:

Yeah, I'm not super concerned about grades and I teach an aeronautics class now, where it's me and an engineering teacher, and, before I started co-teaching with him, I used to notice that the technology students all got 98s and 99s and 100s on their report cards, and I was like, “That's really ridiculous.” And now I kind of get it – it doesn't matter what the number is; you want the kids to want to come to class and be engaged in the activity. And so if it takes giving them good grades to get that done, I guess I'm all right with that now.

This teacher intended to de-emphasize grading related to engineering tasks as a means of motivating students to engage in the process rather than focus on generating a perfect product. He hoped that “to get students to have fun might be the best motivator for them to continue to do it, regardless of grades” and planned to apply that in the design of his physics-integrated engineering lessons.

Despite the potential for pushback from students, the teacher participants expected that they could overcome student resistance and they agreed that the incorporation of engineering in their class would ultimately increase student engagement. With time, teachers expected students to respond positively to this new teaching and learning dynamic. Some teachers had already experienced this in their classrooms. In his reflection following the workshop, Jack was realistic about his expectations for engineering in his classroom. He had accepted that the integration of
engineering would be a challenge initially but that most students would eventually embrace the change:

I think they'll love it as long as it’s done well. Obviously, the first time it will be awful and the second time it will be pretty awful. They love doing labs, they love doing things so I think they would love – well, some of them will hate it though. I think in general it will be something kids will like to do. If it was something we were doing in class over the course of a few weeks, I think they might be excited to go to physics to get back to work on their project. Maybe that’s just wishful thinking that they would be excited to go to physics but I think they would be. If they are exposed to it the right way, they will realize that it’s not scary or it’s not boring or whatever, whatever their fear about it was, I think they'll realize that it’s not those things. And it also could totally just not be for them and that’s okay.

Teacher participants who had already attempted engineering instruction had witnessed this shift from reluctance to acceptance and enjoyment in their students. Lydia enthusiastically shared her experience after making adjustments to her presentation of engineering following the workshops, “They were so engaged. Class management wasn't even an issue. It was phenomenal.” This teacher was not confident in her understanding of engineering prior to the workshops. While she had attempted to incorporate engineering, the tasks she had described lacked some key elements of the design process. Initially, she did not identify student engagement or excitement as a benefit of engineering in her science class. As detailed earlier, after the workshops, the lessons she employed in her biology class enabled students to practice engineering more authentically. Lydia used her experience in the workshops to inform the design of her lessons and saw a more positive response from her students. The changes she made to align her instruction to the NYSSLS, based on her experience in the workshop, alleviated some of the frustrations both she and her students had experienced previously creating a more positive teaching and learning experience.

A comparison of science teachers’ descriptions of engineering in the classroom before and after the workshops provides evidence that the structure of this short-term professional development facilitated change in teachers’ perspectives, confidence, and behavior in engineering instruction. Teachers demonstrated growth in their understanding of the engineering design process and its relevance to their science course content. Following the workshops, teachers were able to use the knowledge gained to describe manageable curriculum revisions that would accommodate addressing the engineering practices while simultaneously covering specific science content. Teachers’ visions of engineering lessons shifted from disconnected, overwhelming projects before the workshops to integrated modifications to existing science content and skill-specific activities following the workshops. Teachers also demonstrated a transition in thinking of engineering tasks as modeling activities focused on a product to envisioning engineering as a process in which students engage in solving problems through optimization. After the workshops, teachers indicated that they were prepared to facilitate more student-centered engineering lessons that allowed students ample opportunity for decision making during the design process while providing support to students who might initially be resistant. Teachers demonstrated a greater sense of confidence in their ability to plan and carry out appropriate and relevant engineering lessons in their science courses after participating in the workshop series. The participants’ statements indicated that some teachers had already made changes in their classrooms to move
towards NYSSLS engineering alignment. The rest of the teachers demonstrated engineering instruction competencies and continued motivation to enact reform in the future.

**Encouraging engineering futures.**
A primary objective in the development of the NGSS document was to increase student motivation to pursue careers in engineering fields in hopes of closing the anticipated gap between job vacancies and qualified workers (NRC, 2012). The choice by students to pursue paths in engineering requires awareness of the available job opportunities and the preparation required to be qualified for those engineering jobs, as well as a sense of self-efficacy in meeting these career aspirations (Kolmos et al., 2013; Matusovich et al., 2010). During the workshops, teacher participants were provided with information about the engineering courses of study offered at the university hosting the series. It was intended that these resources would enable teachers to provide guidance to their students interested in pursuing engineering careers. The teachers all responded positively to this component of the workshops, recognizing that it was a novel area of instruction that had not been addressed in other professional development activities. Having had different experiences in the past with engineering, the teachers entered the workshops with varying degrees of confidence regarding engineering training and careers. Generally, the teachers felt more prepared to help their students navigate engineering pathways following the workshops. Two themes emerged during the interviews as areas of concern for teachers regarding student preparation for engineering futures. Teachers reflected on their ability to help students prepare for future engineering fields of study through pre-college course advisement, as well as their ability to direct students towards specific engineering fields based on student interests and aptitude. These themes are summarized in Figure 7.

![Figure 7](image)

**Figure 7.** Theme 4: Encouraging engineering futures.

**Preparation for engineering study.**
All of the teachers acknowledged having students express an interest in engineering as a career choice. The distribution of students demonstrating engineering aspirations varied by subject area and level taught. Of the interviewed participants, the physics teachers more often identified having students approach them about engineering than the biology teachers. Additionally, based on interview responses, high school teachers, particularly those teaching higher-level (i.e., Advanced Placement) science courses, more frequently answered questions about engineering futures than middle school or non-accelerated course teachers. Prior to the workshops, most teachers admitted that they lacked confidence in their ability to provide guidance for students considering engineering career paths. Some teachers said they would refer interested students to their school guidance counselors or other teachers for assistance in planning for college and careers. Only two teachers were able to identify engineering-specific elective offerings in their district designed specifically for students who were likely to pursue engineering. After the workshops, several teachers said they felt more prepared to help students plan to pursue engineering as a field of study in college than they had prior to the workshop. This included making recommendations for other high school coursework and guiding students towards a particular engineering field of study. One
teacher said, “I think that discussion we had, getting a better sense of it, is definitely going to help me guide kids. I think I have a much better handle on it.” For students considering engineering futures, many of the high school science teachers advised taking advanced-level science and mathematics classes, specifically physics, chemistry, and calculus. Additionally, two of the teachers suggested students develop programming experience by taking a computer science or coding course offered at their school. One teacher placed significant emphasis on this saying, “The number one thing you can do for yourself before going to engineering school is take a computer science class.”

**Engineering career awareness.**
The electrical engineering workshop included a lengthy discussion regarding engineering career pathways. Due to timing limitations, the topic was not addressed in as much detail during the biology workshops. Teachers in the electrical engineering series demonstrated growth with regard to explaining the diversity of engineering fields and related careers. Participants entered the experience with varying levels of confidence in their ability to differentiate engineering fields. Those teachers with little awareness prior to the workshops reported feeling more confident about educating students regarding career options than they did in pre-workshop interviews. Teachers were very appreciative of the posters they received and most had hung the posters in their classrooms, encouraging student questions and conversations about engineering fields. One teacher said of the posters, “I hung up all those posters that you gave us in our classroom and kids go up to them, they read them, and they’re interested, and they ask – it’s a conversation-starter.” Some of the teachers expressed interest in receiving even more instruction on the engineering disciplines to acquire resources to share with their students in the classroom. Participants in the biology workshop series showed no evidence of change in their ability to characterize different engineering fields. This disparity suggests that facilitated instruction on the topic of engineering career awareness could be effective in this type of teacher professional development.

Before the workshops, many teacher participants were motivated to learn more about engineering instruction, in part, to promote student awareness and interest in career opportunities in the field. Teachers, however, were admittedly uninformed about pre-college planning for the diversity of engineering fields of study making this component of the workshops highly productive. Teachers valued the engineering careers conversations, particularly during the electrical engineering workshops during which a large portion of one session was dedicated to the topic. The posters distributed to teachers during that workshop supported the ultimate goal of the professional development to influence student awareness of engineering as many teachers eagerly shared the posters in their classrooms. Based on teachers’ continuing misconceptions about engineering preparations, it became apparent that teachers needed additional support to help their students develop a strong foundation for success in an engineering pathway during high school.

**Obstacles to integrating engineering.**
Despite their motivation to implement the engineering practices in their classrooms, the teacher participants were concerned about potential obstacles to implementation. Three themes emerged from conversations with the six teacher participants regarding obstacles, which centered on time, materials and resources, and congruency with standardized assessments (Figure 8). With the limited time that had elapsed between pre- and post-workshop interviews, there was little change in teachers’ expectations about these obstacles for the duration of this study.
Every teacher identified time as a limiting factor in enacting change in the classroom. Many teachers already felt pressure to complete their course and prepare students for the associated standardized state assessments. They worried that adding additional standards onto their already rigorous content would prevent them from attaining the science learning objectives students were expected to demonstrate by the year’s end. Throughout the professional development experience, some teachers maintained their concerns that the integration of engineering into their course would require a sacrifice in the coverage of science content central to their course. After the workshops, Pedro expressed his reservations:

There are very few lab activities that have the flexibility and that design in Regents level classes where you have a core curriculum to get through. And time is kind of a precious resource. The time allowing a kid to – it comes at a compromise. That's one of the things we all discover when we are pushing other activities into it. You can take from somewhere else, you can't get everything put in or you get behind in timing, and eventually something else drops.

He recognized that his existing curriculum had not provided the opportunity for many NYSSLS-aligned engineering activities. He expected that in order to appropriately prepare his students to meet the engineering standards he would have to sacrifice time spent on the science laboratory activities that had successfully supported student learning in the past. While time limitations were a concern for many teachers, Pedro’s justification suggested a continued misconception that engineering engagement would be tangential to the science content rather than integral.

Richard reiterated the anticipated need for compromise due to time constraints. As he explained from his perspective addressing the science content would ultimately take precedence over the implementation of specific science and engineering practices in most classrooms:

I think right now, there's still a disconnect. I think everyone is still kind of content driven. I think if you get opportunities like what we just had, you can see where it's easy to infuse it into any part of the curriculum. Right now, people generally still don't see the connections 100%, especially after just talking to people at the workshop, and having a chance to really think about it. I think because we're still all worried about making sure we cover all our content. Where are we in terms of pacing? I think that sometimes takes precedence.

Following the workshops, Richard himself did not view time as a prohibitive factor in implementation. He had made the important realization that science course content need not be compromised in order to address the engineering practices. Richard acknowledged that while he gained perspective through participation in the workshop series, he had also noticed that his colleagues who had not had the same opportunity maintained their belief that this reform would
necessitate sacrificing science content. In his role as a teacher leader, it was anticipated that he would address this misconception with his colleagues as he shared the resources he obtained during the workshops.

An additional concern for some teachers was the limited time they had for planning and updating their curricula to accommodate the engineering standards. One teacher identified this as his biggest obstacle, “It’s a matter of finding the time to sit and retool what I do and getting time to do that.” Lydia shared this view of planning time:

I could actually see how it could work. Yes, it could. I'm going to give you the answer that I hate that other teachers say is I just don't have the time. Yeah, so it absolutely could – it could definitely supplement and enhance the eighth grade – it absolutely could. I need time to plan it and design it myself and then implement it. I just haven't done that.

During the interviews, Lydia described several lessons she had designed to engage students in engineering. She was clearly very motivated to make changes and appreciated the value of engineering for her science students. Yet, she continued to struggle as a teacher with many demands in her day to be able to dedicate the time she felt would be necessary to make updates to her lessons.

**Materials and resources.**

Some teachers expected accessibility to resources to be an additional obstacle to utilizing engineering activities in the classroom. However, these concerns varied considerably among teachers in different school districts. Lydia and Sophie taught in districts with more limited financial resources than the other participants. Sophie described how restrictive the science materials budget was in her district, “We don’t have a lot of resources. We have probably more than 20 biology teachers. Our budget for those teachers is $3,000 for the year.” With the limited available funds, she and her colleagues felt pressure to invest wisely in materials that could be utilized most effectively for a large number of students over many years. She explained that many teachers in her district purchased materials for classroom use with their own money without reimbursement from the school. Sophie worried that doing projects like the fuel cell that was constructed in the biological engineering workshop would not be accessible to her and her colleagues because of the cost of materials.

In addition to accessibility to supplies, Lydia found it difficult to implement some NGSS-aligned engineering lessons because of the lack of technology in her school:

But supplies were a big concern for me. We have no access to technology. So they weren’t able to research a design, really – either they did it at home or they were just literally brainstorming by using pictures from a textbook, which is difficult. But they need to see something working first. It’s hard for me, quite frankly, to get a 13-year-old who doesn’t have exposure to that stuff in the past to try and just get it out of nowhere. So technology is a huge obstacle for us.

Lydia’s concern here was two-fold – she expected her students to have limited knowledge in engineering and she lacked access to resources for students to reference. She was worried that her young students, with little to no experience in engineering, would not be able to conceive of
solutions to problems with which they may not be familiar. With limited accessibility to computers and digital information, she felt she would not be able to sufficiently contextualize the engineering tasks she expected her students to complete.

**Congruency with standardized assessments.**

When New York State adopted the new P-12 Science Learning Standards in 2016, no changes were made to the existing standardized state assessments in science, which were aligned to the previous standards. The state anticipated administering updated science assessments at the elementary and middle levels beginning in 2022 and revised high school assessments, called Regents exams, in 2023 (NYSED, 2019). Prior to the adoption of the NYSSLS, students were not accountable for demonstrating competency in the engineering practices as these were not addressed in the previous standards as they were in the new NYSSLS (NYSED, 1996, 2016b). Therefore at the time of this study, teachers were expected to align their instruction to standards that were different than those being assessed on state standardized exams. Several teachers commented on the incongruence between teaching expectations and assessment objectives as a challenge to classroom reform.

Many teachers found it difficult to justify the investment in engineering instruction as long as it was not being assessed on end of course examinations. One teacher said his primary focus was “getting the curriculum done and gearing the class towards the Regents [exam].” Pedro explained his rationale for the format of his course:

> Much of it is going to come down to where the state education department is – and this is horrible to say – in their development of an assessment piece – not that we always teach to the assessment but the assessment piece helps staff understand what really should be understood then by the student.

While this teacher had previously identified a value in engineering instruction, here he admitted his reluctance to align his instruction to the new standards as he feared that making the change prematurely would result in his students being unprepared for the Regents exam. He, and other teachers, used the state assessment that had traditionally been aligned to the state standards as a guide for their instruction and practice throughout the year. Jack expressed the same concerns,

> I think if I wasn’t teaching a Regents class with that assessment at the end, I think I would be able to figure out how to teach a physics course with lots of engineering. Now with the Regents based on the old standards and trying to incorporate the practices of the new standards, I had to teach two months’ worth of physics [in one month] because I did too much science and engineering practices in September through December. So doing that on top of everything seems like a big challenge.

Jack expressed some regret about trying to align to the new standards. He worried that he had committed too much time to addressing the new NYSSLS student practices and in doing so had compromised his students’ preparation in some of the content that would be assessed on their exit exam. This attitude was likely to limit the implementation of the NYSSLS prior to the 2023 testing changes.

Additionally, some teachers expected that students would be resistant to instruction that did not directly align to the course’s standardized assessment. Many teachers at the high school level
had observed that students’ primary academic motivation was related to their grades. Teachers feared that students would be less likely to engage in tasks that were not directly related to their summative course assessment, especially if they expected that those activities would adversely affect their grades. Joseph expressed his concerns related to student motivation in engineering:

When students see that what they're doing does not directly relate to their assessment, sometimes, they don't take it seriously and that would be something that would be very difficult to overcome. That would be a big obstacle.

This teacher had previously experienced students’ lack of investment in tasks not specifically tied into the course objectives and assessment. He expected his students might not put their best effort into engineering projects if they did not anticipate that it would be tested later in the year. Another teacher said more bluntly, “the kids and the parents are so geared towards getting high marks on tests that they want everything to be based on the Regents exam.” Pedro felt the same about his honor middle school students:

Especially if you're in a district with a higher academic standard or desire they are going to want to do well. They can go along for the ride but they're going to want to get out of it what shows on their transcript.

When introducing lessons, Pedro often found his students were most concerned about the impact of classroom activities and assignments on their grades. He worried that students might react negatively to engineering tasks in the classroom as the novel nature of the assignment would lead students to feel they were unlikely to be successful, resulting in adverse effects on their grade.

For some teachers, the motivation to align classroom instruction to the existing assessments rather than the adopted standards was related to the teacher evaluation system. In many schools, teachers’ performance evaluations were based on their students’ performance on these standardized state exams, which discouraged pedagogical reform (Mintz & Kelly, 2018). At the time of this study, there was little incentive for a teacher to modify the instruction that had effectively prepared students for the state assessments for years. In fact, teachers worried their evaluation might suffer if they did adopt a more NYSSLS-aligned curriculum prior to the anticipated changes to the exams.

The concerns discussed by teachers in this study were consistent with the obstacles that had hindered reform efforts in the past (Cohen & Spillane, 1992). Even teachers who were motivated to adapt, like the participants in these workshops, felt that the availability of time and materials limited their ability to change their teaching to align with the NYSSLS. The integration of engineering into the science curriculum was entirely novel in New York State and teachers feared they would have to sacrifice some of the robust science content of their courses to address the engineering standards. The workshops helped to address this concern for some teachers but others maintained this perception even after their participation. The delay in testing reform is a significant factor preventing many teachers and school districts from committing to NYSSLS implementation. Teachers and students were evaluated by scores on state assessments which, at the time of this study, were not yet aligned to the new standards. Teachers continued to align their instruction with the previous state standards to ensure students were prepared for these high stakes exams at the conclusion of each science course.
4.5 Summary

The quantitative results and qualitative findings provided convergent evidence for teacher growth in engineering pedagogical knowledge and confidence in engineering instruction following participation in a multi-session engineering education workshop for science teachers. Overall, teachers demonstrated an increased appreciation for the value of engineering instruction in their science courses, a clearer vision of engineering activities in the science classroom, and a broader understanding of engineering as a career.

The interviewed teachers expressed change in their assessment of the value of engineering in their science classrooms. Following the workshops, teachers expected that the use of engineering activities would facilitate student learning in science and the development of essential science skills such as critical thinking, collaboration, and problem solving. Survey responses reflected the same themes as teachers demonstrated increased abilities to encourage student participation in creative and critical thinking and interaction through engineering activities. In surveys and interviews, teachers expressed increased confidence in their ability to make connections between engineering and science and use engineering lessons to transfer science knowledge to real-world contexts. Teachers anticipated that this would motivate students to more actively engage in science learning and possibly consider future careers in science and engineering.

Teachers showed growth in their pedagogical engineering confidence in several areas. In surveys, teachers showed a significant improvement in their self-assessed confidence in recognizing and appreciating engineering applications in their content areas. This was demonstrated in interviews as participants were able to more precisely describe lessons that appropriately addressed both science and engineering practices following the workshops. Survey responses indicated significant growth with regard to teachers’ abilities to employ engineering activities, guide students in engineering solutions development, and assess students’ engineering processes and products. The interviewed teachers reflected on their experiences in the workshops and re-envisioned future interactions between themselves and students during engineering activities to allow for more authentic design experiences in the classroom. According to survey responses, teachers demonstrated significant improvement in their ability to differentiate between engineering careers and inform their students about these career options. The interviewed participants were appreciative and made immediate use of the classroom-ready resources they received during the workshops. They were able to share the posters and their own engineered products with their students to initiate conversations about engineering career paths. Teachers developed confidence in their ability to provide guidance to students about high school course taking in preparation for future engineering study, increasing the accessibility of college engineering for students.

Despite their personal growth in several domains of engineering instruction, the interviewed teachers expressed continuing concerns related to impediments to the integration of engineering in their courses. As is often the case with reform efforts, teachers felt they did not have the sufficient resources or planning time in their schools to develop new resources and modify existing lessons to align to the new standards. This was supported by the survey questions regarding curriculum modification to align with the NYSSLS. Additionally, the interviewed participants were struggling to address the new learning objectives, including those in engineering, while continuing to prepare students for standardized assessments that emphasized antecedent standards. A summary of these convergent quantitative results and qualitative findings is presented in Table 9.
Table 9. *Convergent Parallel Summary of Quantitative Results and Qualitative Findings*

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Quantitative Results</th>
<th>Qualitative Findings</th>
</tr>
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<tbody>
<tr>
<td>1. How does professional development in engineering education affect secondary school science teachers’ beliefs about the value of using engineering design to support science learning?</td>
<td>Following the workshops, teachers reported a greater sense of confidence in their ability to use engineering to develop science skills, such as critical thinking, creativity, and collaboration. Teachers also demonstrated significant growth in their ability to make associations between engineering and science.</td>
<td>After the workshop experience, teachers expected that the inclusion of authentic engineering tasks in their science classes would benefit students by increasing their interest and performance in science while developing their scientific skills. Additionally, teachers anticipated inspiring more students to consider engineering careers in the future.</td>
</tr>
<tr>
<td>2. How does professional development in engineering education affect secondary school science teachers’ self-efficacy regarding teaching engineering in their science courses and providing advisement for engineering careers?</td>
<td><em>Teaching engineering:</em> At the conclusion of the workshops, survey respondents reported large improvements in their ability to engage students in engineering tasks, guide students in the design process, and assess students engineering products and skills. Teachers demonstrated less significant or no growth with regard to lesson development and alignment to state standards.</td>
<td><em>Teaching engineering:</em> Interviewed participants demonstrated more definitive connections between engineering and science after the workshops. Following participation in the workshops, teachers were able to describe detailed science lessons they enacted or intended to employ that appropriately integrated engineering. Teachers considered the changes in classroom dynamics during engineering activities and considered the response of students in their planning.</td>
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<td></td>
<td><em>Career advisement:</em> Participants demonstrated significant growth in their ability to provide guidance to students intending to pursue engineering futures. After the workshops, teachers reported feeling more prepared to inform students about engineering career options and to assist students in planning their precollege coursework.</td>
<td><em>Career advisement:</em> Following the workshops, teachers felt more prepared to differentiate various engineering fields of study and careers. Teachers also believed they were more prepared to offer advice to students during their high school course planning related to course selections in science and mathematics.</td>
</tr>
<tr>
<td>3. What obstacles do science teachers identify during the implementation of engineering practices in their science classes?</td>
<td></td>
<td>The interviewed teachers identified the availability of time, instructional materials, and resources as limits for engineering instructional opportunities.</td>
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The lack of coherence between state standards and standardized exams was also a factor restricting implementation.
Chapter 5

Discussion

5.1 Introduction

The present study interprets the influence of science teacher professional development in engineering on teachers’ evaluation of engineering instruction and self-efficacy in teaching engineering and providing engineering career guidance. Through the analysis of qualitative and complementary quantitative data, there is evidence to support the investment in this model of teacher professional development to increase teacher confidence in engineering teaching and motivation to implement classroom change. As NGSS adoption continues throughout the U.S., it is imperative that teachers receive effective training in all aspects of the reform but particular attention must be paid to the engineering standards, as this is a novel addition to the science curriculum. The teacher training studied here provides a model for professional development that requires minimal investment of time and financial resources with significant impacts on science teachers’ ability to successfully integrate engineering design and career advisement in their science courses.

This chapter begins with a discussion of the results and findings as they relate to existing research in the field of science and engineering teaching. Section 5.3 highlights the implications of this study for various stakeholders, including science teacher educators, district administrators, science education policy makers, science teachers, and students. Finally, limitations of this study are identified and suggestions for future research regarding science teacher engineering professional development are discussed.

5.2 Discussion

The interconnected model for professional development provided the framework for the analysis of teachers’ response to involvement in this engineering professional development experience (Clarke & Hollingsworth, 2002). Findings and results showed evidence of the influence of the workshops, as the external domain, on teachers’ personal domain and domain of practice. The resulting change in teachers’ conclusions about engineering in the science classroom, within the domain of consequences, provided a means of reinforcement for teachers as they reflected on their workshop experience and implemented engineering instruction through newly acquired pedagogical strategies. The initial conceptual framework (Figure 2), based on the interconnected model for professional development, illustrated the intended target areas for teacher growth based on their participation in the workshop series. Figure 9 illustrates a revised framework based on the findings of this study, demonstrating specifically the influence of engineering professional development on science teachers’ professional growth. This study provides evidence that teachers demonstrated growth in engineering instructional knowledge, valuation of engineering in science, ability to integrate engineering and science, and ability to influence colleagues through collaboration as a direct result of their participation in the professional development workshops.
As a result of this personal and practical growth, teachers reported classroom benefits such as increased student engagement, interest, and motivation in both science and engineering.

**Figure 9.** Analytical framework of engineering professional development and teacher professional growth.

**External domain: Engineering professional development.**

The university-based engineering training served as an external influence contributing to science teachers’ engineering content and pedagogical knowledge and engineering career awareness. Based on the existing research on teacher professional development and the situative perspective of learning, the experience addressed a pre-existing gap in teachers’ awareness of the NGSS engineering standards through collaborative engagement in the engineering design process facilitated by instructors representing the engineering and science education departments (Darling-Hammond et al., 2017; Putnam & Borko, 2000; Supovitz & Turner, 2000). While much research supports professional development through sustained long-term experiences, this study provided evidence of the positive impact of this short-term (four to six hour) model of in-service training on teacher growth (Darling-Hammond et al., 2017; Yoon et al., 2007). In particular, the classroom-ready resources designed for teachers to take back to their classroom (the engineering design projects and engineering career posters) provided an opportunity for teachers to engage students and colleagues in conversations about engineering as soon as they returned to school.

This study offers unique insight into the experience of science teachers learning engineering and engineering pedagogy in alignment with NGSS. The majority of previous analyses on engineering professional development has focused on programs designed for technology or engineering teachers or training for specific curriculum programming or resources (Daugherty, 2010; Singer, Ross, & Jackson-Lee, 2016); little research exists on programs supporting the integration of science and engineering specifically for science teachers. Teachers in this study were introduced to new information about engineering careers and pre-college engineering advisement for students. While it is known that teacher influence is a contributing factor in student post-secondary study and career choice (Moore, 2006), targeting engineering career awareness during
science teacher professional development has not been well documented in the literature. This study provides evidence that science teachers can benefit from specific instruction about engineering courses of study and careers.

**Personal domain.**
Following their experience in the workshops, teachers demonstrated growth within their personal domain of engineering and science teaching. Measurable gains in participant confidence to establish a productive classroom environment and engage students in enriching engineering tasks were evident. Teachers specifically demonstrated significant growth in their ability to guide students through the engineering design process and assess their progress in these engineering tasks. Through their involvement in classroom-ready activities during the workshops, teachers gained insight into the student experience, which aided in their planning and enactment of engineering lessons in their own science classrooms. This builds on the existing research on the situative perspective of cognition, providing evidence for the value of engaging science teachers in the engineering design process as they prepare to address the engineering practices (Putnam & Borko, 2000). Initially, teachers expressed a lack of awareness of the NGSS engineering practices and their relationship to the science content, supporting the need for this type of science teacher learning experience (Bybee, 2014).

Over the course of the study, teachers refined their vision of engineering in the science classroom. Following their experience in the workshops, teachers were capable of identifying manageable and appropriate approaches to embedding engineering within their science lessons to support student learning in both science and engineering. This study provides evidence that this model for professional development may positively influence engineering self-efficacy and awareness in science teachers regardless of their content area specialization. Based on the integrated model for professional growth, it was expected that this change would support growth in the domain of practice as teachers enact engineering-aligned lessons in their classrooms (Clarke & Hollingsworth, 2002). Although the interviewed teachers showed development in their ability to innovate NGSS-aligned engineering lessons, survey responses indicated that teachers did not experience growth in their confidence to be able to modify their curriculum to satisfy NGSS. This is not unexpected as these workshops were not designed to provide specific support in lesson design. The lack of teacher confidence in lesson development might impede classroom integration. These findings suggest that more attention should be paid to lesson design and curriculum alignment in future workshop sessions to enable teachers to expand the applications of engineering within their science course content beyond the subjects addressed during the workshops.

Some of the most significant developments in the personal domain of teachers were their increased awareness and confidence regarding engineering college and career advisement. Even before the workshops teachers valued engineering instruction as a means of motivating students to consider engineering futures, however, they often felt unprepared to answer students’ questions or provide direction to students with an interest in engineering. After instruction about different engineering careers and high school preparation required for engineering majors, teachers reported feeling more confident in their ability to advise students in these areas. Participants who received the engineering career posters were excited to share these resources and engage in conversation with students about potential options for their futures. This study provides evidence that science teachers can benefit greatly from exposure to resources about engineering career advisement. It has been established that teachers play a critical role in student career planning (Moore, 2006),
therefore, it is expected that this investment in teacher professional development will positively impact students.

Successful education reform relies, in large part, on teacher acceptance of the change (Haney, Lumpe, Czerniak, & Egan, 2002). The integration of engineering education in science classrooms throughout the U.S. is most likely to be successful if science teachers recognize a value in their efforts to realign their curricula. The responses from teachers participating in this study indicate that the perceived value of engineering in science education can be augmented through professional development. At the conclusion of the workshops, teachers attributed many benefits to engineering instruction for their students. In addition to providing students with exposure to careers options, teachers also expected that engineering would improve student engagement, interest, and performance in science. The interaction in engineering activities during the training also empowered teachers with a greater sense of confidence regarding their ability to promote the development of students’ science skills through engineering. The findings of this study suggest that teachers can develop a greater sense of worth regarding a reform effort with appropriate support and lesson modeling. Establishing this motivation for teachers is necessary to ensuring the integrity of the NGSS during adoption and implementation (Haney et al., 2002).

**Domain of practice.**

Following their participation in the workshops, teachers also demonstrated change in their domain of practice related to engineering instruction. Survey responses demonstrated that significant growth occurred in teachers’ confidence to integrate science and engineering in the classroom providing real world, content-specific relevance in order to support the development of students’ science skills. This study provides evidence that teacher engineering instruction self-efficacy can be positively affected by experiences that provide opportunities for observation of and participation in engineering instructional activities in a supportive collaborative setting. While classroom observations were not conducted as part of this study, teachers provided reflections of their classroom implementation process during post-workshop interviews. Shortly after the conclusion of the workshops, motivated by their newly developed confidence in engineering teaching, teachers started planning or experimenting with engineering instruction in their science classes. The lessons that teachers described following the workshops drew concrete connections between their science content and practices and the engineering practices. The redesigned lessons demonstrated a deeper understanding of the engineering design process as teachers established new roles for themselves and their students in the classroom, shifting more control of the experience to the students. Additionally, teachers discussed realigning the assessment of classroom engineering tasks to focus on the design process rather than the engineered products. These changes in classroom practice provided evidence of the situated learning teachers experienced through participation in the classroom-ready activities during the workshops (Putnam & Borko, 2000). This approach to engineering professional development can support pedagogical growth leading to effective implementation of engineering instruction.

The domain of practice also includes the interactions of teachers with their colleagues; as teachers experience personal growth they influenced and were influenced by other educators (Clarke & Hollingsworth, 2002). As state-recognized Master Teachers, the participants in this study had previously been identified as teacher leaders in their schools. Having already established themselves in this role, the participants in this study were in an ideal position to support the development of engineering confidence and awareness in other educators. Motivated by their experience in the workshops, teachers interacted with colleagues in their districts by facilitating
in-service workshops and cooperatively planning engineering-aligned lessons. These findings suggest that investing in training for teacher leaders early in the adoption process can be an effective means of influencing wide-scale teacher change with limited resources.

**Domain of consequence.** Teachers’ ongoing growth in engineering pedagogy is expected through reflection on their progression in both the personal domain and domain of practice. Survey responses demonstrated that teachers felt more prepared to be able to promote a positive student attitude towards engineering in their classroom to increase student interest in the field. Teachers who had begun implementing engineering integration in their science classes were considering the response of their students to the innovation as they continued to refine their vision of engineering instruction. Teachers who witnessed increased engagement and excitement from their students were encouraged to continue adapting lessons to include elements of engineering design. Teachers who anticipated trepidation on the part of their students intended to modify their engineering adoption to provide more scaffolding as students work to develop necessary skills. Students’ reception to engineering career information was especially motivating for teachers who were eager to support students’ pursuit of engineering futures. Evidence of continuing independent teacher growth suggests that this intervention may have lasting impacts on a teacher’s practice.

**Professional growth environment.** The interconnected model of professional growth recognizes the significance of the teaching environment on a teacher’s professional development. In this case, the environment of growth can be defined as the physical teaching locale as well as the state-supported Master Teacher Program, in which all study participants were involved. As the teachers explained, the meetings they attended regularly as part of the program provided the foundation for their pre-workshop awareness of NGSS, as well as a forum for continuing professional growth following the workshops. While previous research has identified long-term high-contact time teacher training as most effective, this study provides evidence that short-term learning experiences paired with ongoing informal teacher collaboration was sufficient to have a transformative impact on teachers’ perceptions and intentions regarding their practices (Darling-Hammond et al., 2017).

Teachers identified a number of ongoing concerns related to their school districts and state policies that were likely to impede their progress in engineering integration. The most significant concern was the lack of coherence between the newly adopted NGSS-aligned state science standards (NYSSLS) and the state standardized assessments. Teachers and school districts were reluctant to invest too quickly in engineering alignment for fear they would be sacrificing too much classroom time on content that would not be assessed on the state exams for several more years. The results of these exams have high-stakes implications for students with regard to graduation and for administrators and teachers concerned about professional performance evaluations (Mintz & Kelly, 2018). The findings of this study confirm that even with effective professional development, full-scale engineering integration will be limited until changes are made to the standardized science assessment protocol.

Discussions with teachers also revealed that standards implementation varied widely between districts. In some schools, teachers had abundant resources and support from administrators to move towards engineering integration in science. In other locations, teachers were struggling to obtain materials or were receiving no encouragement from district leadership to make curriculum changes. Lack of consistency in implementation has hindered the success of previous reform
efforts (Anderson & Helms, 2001; Fullan & Miles, 1992). The findings of this study identify this as a continuing concern regarding the long-term influence of NGSS.

5.3 Implications

The results of this study provide insight into the development of engineering awareness and confidence in science teachers as they attempt to align their instruction to the latest science education standards outlined in NGSS. As the interconnected model for professional growth suggests, the development of teacher self-efficacy and knowledge happens within the context of various environmental influences (Clarke & Hollingsworth, 2002). Ultimately, teachers need support from a network of colleagues, innovative administrators, and state policy makers in order to successfully carry out reform in the classroom to benefit student learning and achievement (Slagus, 2019). The findings discussed earlier in this chapter suggest a number of implications to consider as efforts are made to reform science education through NGSS. A summary of the implications of this research are presented in Figure 10.

![Figure 10. Summary of implications of study findings on various stakeholders.](image)

Science education policy makers.

The adoption of the new state science standards based on NGSS in New York in 2016 marked a shift in science education in the state; the prior standards had no expectation of engineering inclusion in science curricula and no requirement for engineering training for science teacher certification. The findings of this study suggest that without intervention, science teachers will be unable to provide effective engineering instruction to support students’ science knowledge acquisition when state standardized assessments change in 2022. State policy makers must consider modifications to the adoption process to mitigate these issues and ensure a greater likelihood of implementation of the standards as they are intended.

With the present vast gap between science teacher engineering knowledge and the new science learning standards for students (Banilower et al., 2013; Christian et al., 2018), it is necessary to reassess the requirements for science teacher certification. At the time of this study, coursework in engineering or engineering education was not a requisite for science teacher certification. In
fact, coursework in applied engineering subjects were excluded as acceptable science credit for teachers applying for certification. The \textit{NSTA/ASTE Standards for Science Teacher Preparation} provides a framework for teacher certification programs that are aligned with NGSS student learning expectations and makes specific mention of the role of engineering to support science learning (Morrell, Rogers, Pyle, Roehrig, & Veal, 2019). New York State, and others in the process of standards reform, must reframe science teacher preparation to specifically include training in engineering and engineering pedagogy. This could effectively be accomplished through the incorporation of elements of engineering instruction within already required science-content specific coursework. This study supports the situated learning context for engineering knowledge and pedagogical content knowledge acquisition for teachers and may serve as a model for science teacher preparation courses in engineering. Following these changes in teacher preparation, state education policy makers must be prepared for a lengthy progression in engineering implementation as new teachers with greater engineering awareness enter the field.

The continued progression of the STEM education movement and the adoption of updated standards like NGSS are not cohesive with the structure of the secondary school experience. The present schooling system, established over a century ago, compartmentalizes the educational process into discrete subject areas each with a prescribed set of requirements for students to satisfy before high school completion (Tyack & Tobin, 1994). The nature of the STEM movement challenges this archaic system through the integration of science, mathematics, technology, and engineering. As the scope of the science curriculum grows to include other disciplines and the expectations of science teachers expand to address a greater range of content and skills, the distribution of time students spend in science and the credits they earn during high school should be reviewed. Currently in New York State, students must complete four credits of coursework each in English Language Arts and history, but are only required to satisfy three credits (equating to three years of study) each in mathematics and science with no requirement for engineering coursework (NYSED, 2017). Students should be required to complete one year of science study for each of their four years in high school, particularly due to the critical importance of science literacy for all students. The findings of this study show that teachers are struggling to find adequate time to address all of the expectations set forth by the state education standards. Redistributing the science learning objectives over four years would enable teachers to address the standards more thoroughly and empower students with additional exposure to science and engineering before completing high school.

To support teachers in their efforts to meet the demands of this reform and ensure that all students receive the learning experiences intended by NGSS, state policy makers must be transparent in their expectations and provide explicit support to teachers as they align to NGSS. Teachers in this study were struggling during a transitional period to compromise between teaching to the new standards and preparing students for outdated assessments. It has been the case with large-scale education reform efforts in the past that limited continuity of implementation was a barrier to reform success. The variation between the few districts profiled here highlights the need for outreach programs like the one described in this study. Programs specifically targeting teacher leaders from different districts can be a cost-effective investment that can initiate progressive change through the actions of motivated and respected colleagues (Bugallo & Kelly, 2017). The state must make available high quality professional development, classroom-ready teaching resources and sample assessments, and equipment to be sure that all students throughout the state have access to quality science education.
District administration.
A substantial environmental factor affecting teacher professional growth is the school district in which teaching occurs. For a reform as significant as NGSS, an investment must be made to provide teachers with support and resources including funding, classroom space, curriculum materials, and time. Several teachers in this study were concerned that their limited access to resources and support from administration would hinder their ability to fully commit to engineering integration. To support science teacher advancement in teaching engineering, district leadership has an obligation to be informed about the academic standards being implemented. In addition to providing teachers with high-quality professional development to enact NGSS, training should also be provided for district and building administrators to develop a greater understanding of the value of NGSS and STEM integration for student achievement (Bugallo & Kelly, 2017).

The Next Generation Science Standards outline the learning objectives for students in preschool through high school (NGSS Lead States, 2013). As school districts navigate the process of NGSS implementation, it is imperative that the standards are approached as a district-wide initiative. Middle and high school teacher participants in this study expressed concern about their ability to address secondary level engineering expectations with students who were completely naïve about the engineering design process. To enhance continuity from elementary to secondary school, districts should establish opportunities for vertical collaboration between teachers of different grade levels and courses as well as teachers of the same course.

District officials must also be prepared to support the investments in teacher training and resources with teacher accountability for implementation. Some teachers felt that despite district expenditures for professional development for NGSS alignment, minimal classroom change was occurring because teachers did not feel that departmental and building leadership was supervising that change. Clearly defined and upheld standards of expectation for all teachers, enforced by informed administrators responsible for observations and evaluations, may provide additional motivation for teachers to follow through with implementation in the classroom.

Science teacher educators.
The primary intent of this study was to inform the development of professional development experiences for science teachers in engineering. Much of the results and findings have implications for the preparation of future science teachers and training of in-service teachers to incorporate engineering practices in science instruction. Any engineering professional development should reflect three primary objectives: 1) provide teachers with engineering content knowledge, 2) develop teachers’ engineering pedagogical content knowledge, and 3) empower teachers with confidence to engage in engineering instruction. This study provides evidence for several effective strategies to target these goals.

Supported by the knowledge integration framework of cognition, the development of science teachers’ engineering awareness and capabilities requires that instruction challenge teachers’ definition of engineering in order to address initial misconceptions. Reluctance on the part of some teachers in this study was based on their misguided interpretations of engineering instruction. Engaging teachers in engineering tasks allowed teachers to internalize the engineering process and gain insight to the student experience. Teachers reported enjoying the activities and the collaborative structure of the sessions, demonstrating that a hands-on approach to engineering can be engaging for participants. Maximizing teacher involvement in the design process during sessions facilitated the effectiveness of short-term professional development for teacher growth. Carefully selected engineering tasks demonstrating the cohesion between science and engineering
content and practices, provided teachers with a model for developing their own NGSS-aligned lessons. The real world applications of the science and engineering activities resonated with teachers, encouraging them to build those associations within their own classrooms. Instruction on engineering careers and precollege pathways to engineering should be included in any training for teachers in engineering. This novel approach to engineering professional development was a powerful aspect of this experience for teachers who demonstrated growth in their awareness and ability to provide career advisement to students. Empowering teachers and counselors with knowledge about engineering preparation and careers can increase the accessibility of engineering for all students (Gearns et al., 2018).

Because few science teachers have any training or experience in engineering, effective engineering professional development must be made available to a large number of science educators. To address the needs of teachers at this scale, it is necessary to develop time- and cost-effective training opportunities that are likely to impact numerous aspects of teacher growth. This study provides sufficient evidence to suggest that properly framed short-term professional development can lead to growth in teachers with limited engineering awareness. The use of classroom-ready activities to engage teachers in the engineering design process provided the ideal context for development of both engineering content and pedagogical content knowledge. The materials that teachers received to bring back to their classrooms (engineering career posters and engineering project products) facilitated the effectiveness of this short-term professional development as teachers were able to immediately influence colleagues and students with their experience, increasing the sphere of influence of the professional development and minimizing lag time for implementation.

**Science teachers.**
Reform efforts are doomed without the acceptance of teachers (Haney et al., 2002). For their part in this reform, science teachers have an obligation to become more familiar with the NGSS document, in particular the science and engineering practices. At the start of the workshops, teachers admitted to being ignorant of the specific engineering standards and held many misconceptions about engineering instruction. As they developed awareness and confidence of engineering and engineering pedagogy, teachers became more willing to experiment with engineering in their courses. In-service training for teachers based on the intervention described in this study can be used to support teacher growth and preparedness for engineering integration. Particular attention in professional development should be paid to supporting teachers as they attempt to develop and modify curriculum resources and instructional activities to align to NGSS.

**Students.**
The introduction of engineering in the science classroom presents an opportunity for all students to engage in the design process and develop engineering skills. Traditionally, engineering has only been accessible to students who were able to take part in informal experiences, such as camps or afterschool programs (for example, Bugallo & Kelly, 2014, 2015, 2017; Bugallo et al., 2015). Science teacher participants in this study reported increased student interest in science and engineering when they began experimenting with engineering in the classroom. By preparing teachers with the knowledge and confidence to include engineering in the science classroom, more students will gain access to the benefits of engineering instruction. As exposure to engineering instruction has been shown to decrease the achievement gap for Hispanic and Black students in particular, it is expected that an increased capacity for teachers to provide effective engineering
instruction could influence persistence of these often underrepresented student groups in engineering majors, leading to diversification in engineering fields (Cantrell et al., 2006; Mehalik et al., 2008; Roy, 2019). Professional development to improve teacher awareness of engineering careers and pre-college pathways to engineering also has potential to benefit students with expanded advising resources beyond school guidance counselors.

5.4 Limitations

There are limits to the generalizability of these findings. All of the teacher participants had been recognized as Master Teachers and self-selected to participate in this professional development experience. As highly motivated teacher leaders, they reported high confidence in their abilities prior to participating in the workshop series, which is not likely to be the case for all science teachers who need support in engineering instruction. The sample size for quantitative results was relatively small though adequate for statistical purposes. Survey responses were collected immediately preceding the start of the workshops and again at the conclusion of the final session of the series. Quantitative longitudinal data of teacher growth and reflection were not recorded. The sample of respondents for qualitative analysis was also small, yet the emerging themes reached saturation when interview data were analyzed (Guest, Bunce, & Johnson, 2006). While interviews took place several weeks after the workshops, the limited elapsed time prevented some teachers from experimenting with engineering instruction in the classroom. Additionally, all teacher growth was self-reported as no classroom observations were conducted as part of this study. The primary researcher conducting this study was also a high school teacher in the process of implementing engineering and adapting to the new state standards in her own classroom. There is potential for researcher bias in the interpretations of the participants’ experiences and attitudes, although the researcher was careful to acknowledge and bracket these biases through discussion with fellow researchers and iterative case-by-case analysis (Fischer, 2009). Despite these limitations, this study provides evidence for the value of this model for engineering professional development in some settings and provides a foundation for continuing research in a field with significant potential.

5.5 Suggestions for Future Research

Continued research in science and engineering curricular integration and teacher training is required to develop the most effective strategies to support teacher growth in engineering implementation in science instruction. Since few teachers are confident in their ability to teach engineering in the context of core science disciplinary ideas, more training and research in implementing engineering practices in science would be beneficial (Banilower et al., 2018; Christian et al., 2018). Longitudinal studies with additional delayed post-workshop follow up interviews may shed light upon the long-term impacts of this type of professional development, particularly in terms of how teachers’ increased awareness and self-efficacy may translate to pedagogical practice. Observations of teacher enactment of engineering in the classroom would provide more direct evidence of engineering integration. Analysis of the impact on student interest and achievement in science and engineering would also support the use of professional development to contribute to science teacher engineering efficacy. More intensive experiences that involve 50-80 hours of training may have even more pronounced impacts upon teacher practice and student learning (Supovitz & Turner, 2000; Yoon et al., 2007). Alternative sessions focused on professional development for all science content areas, including Earth science and chemistry,
would increase the potential audience of interested teacher participants. The evidence presented in this study provides support for future university-based partnerships between science and engineering faculty and K-12 schools to promote engineering knowledge, design practices, and increased interest and diversity in engineering careers.
References


President’s Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Washington, DC: PCAST.


Tyack, D., & Tobin, W. (1994). The “grammar” of schooling: why has it been so hard to


Appendix A

Engineering Professional Development Survey

Instructions: Some key operational terms are:

Engineering: “A systematic...approach to designing objects, processes, and systems to meet human needs and wants.” (NRC, 2012)

Design: The iterative process of defining engineering problems, designing solutions for these problems, and optimizing solutions through testing and refinement. (NRC, 2012)

1. Please enter four-digit month and date of birth (mm/dd) – to link pre- and post-survey responses only.

2. What course(s) are you currently teaching? (Select all that apply.)
   - Biology
   - Chemistry
   - Computer Science
   - Earth Science
   - Engineering
   - Mathematics
   - Other Science
   - Physics
   - Technology

3. What grades are you currently teaching? (Select all that apply.)
   - 6th
   - 7th
   - 8th
   - 9th
   - 10th
   - 11th
   - 12th

4. How many years of teaching experience do you have?
   - 0-5
   - 6-10
   - 11-15
   - 16 or more

5. Which of the following best describes your completed undergraduate degree program(s) of study? (Select all that apply.)
   - Education
   - Engineering
   - Mathematics
   - Science
   - Other: ________________________________
6. Which of the following best describes your completed graduate degree program(s) of study? (Select all that apply.)

- [ ] Education
- [ ] Engineering
- [ ] Mathematics
- [ ] Science
- [ ] Other: __________________________

7. In the past year, how many times have you engaged your students in the engineering design process while teaching your course content?
- [ ] None
- [ ] 1-3
- [ ] 4-6
- [ ] more than 6 times

8. Have you previously received any professional development to support the integration of engineering pedagogy into your core course content?
- [ ] No
- [ ] Yes   How many hours? (Approximately.) ________________

9. Rate your agreement to each of the following statements.

   *In my role as a teacher, I am able to...*

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Moderately disagree</th>
<th>Disagree slightly more than agree</th>
<th>Agree slightly more than disagree</th>
<th>Moderately agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>explain engineering concepts well enough to be effective in teaching engineering.</td>
<td></td>
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<td>assess students’ engineering products.</td>
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<td>employ engineering activities in my classroom effectively.</td>
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<td>explain the ways that engineering is used in the world.</td>
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<tr>
<td>describe the process of engineering design.</td>
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<tr>
<td>create engineering activities at the appropriate level for my students.</td>
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<tr>
<td>select appropriate materials for engineering activities.</td>
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<tr>
<td>recognize and appreciate the engineering concepts in my subject area.</td>
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</tr>
<tr>
<td>guide my students’ solution development in learning the engineering design process.</td>
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</tbody>
</table>
1. increase students’ interest in learning engineering.

2. help students apply their engineering knowledge to real world situations.

3. promote a positive attitude towards engineering learning in my students.

4. encourage my students to think creatively during engineering activities and lessons.

5. encourage my students to think critically when practicing engineering.

6. encourage my students to interact with each other when participating in engineering activities.

7. inform my students about engineering careers.

8. differentiate between engineering disciplines.

9. recommend relevant high school courses to students interested in pursuing engineering.

10. modify my curriculum to comply with the Next Generation Science Standards (NGSS) and/or the New York State Science Learning Standards (NYSSLS).

11. acquire the resources for implementing NGSS and/or NYSSLS.

10. If you are willing to participate in a post-workshop interview, please enter your e-mail address below.

11. How do you expect to use your experience in this workshop in your classroom?

12. Post-workshop only: Please comment on what you liked best about the engineering education workshop.

13. Post-workshop only: Please comment on how we might improve future engineering education workshops.
Appendix B

Pre-Professional Development Semi-Structured Interview Protocol

1. What was your motivation for participating in this engineering course?
2. Could you describe what engineering is?
3. What personal experience (employment, training, college coursework, hobbies) do you have in engineering, if any?
4. Does your science course, as you teach it, make any reference to engineering?
   a. Yes: Can you share some examples of the engineering you use in teaching your science course? How confident are you in your ability to teach students the practice of engineering design?
   b. No: What has kept you from incorporating engineering into your course?
5. As a science teacher, what concerns you most about teaching engineering in your science course?
7. How have you learned about NYSSLS?
8. Could you identify how the NYSSLS engineering practices are applied specifically to your content area?
9. There are four specific engineering standards in the NYSSLS at the secondary level. Generally, the performance expectations are that students be able to:
   a. analyze a real-world problem
   b. design a viable solution to remediate the problem
   c. optimize their proposed solution through iterative testing.
   How does this engineering model relate to your science coursework, if at all?
10. What value do you see in using a model like the one I just described to teach a concept in your science course?
11. Can you think of specific content from your course that lends itself to incorporating this engineering design process?
12. As of right now, how prepared are you to help students develop the skills associated with the engineering practices?
13. To what extent has your district implemented NYSSLS?
   a. What have you already done in your district to implement NYSSLS?
   b. What plans do you have for NYSSLS implementation?
   c. Do you feel like your district supports the integration of engineering in your subject area?
14. Have you had students approach you about post-secondary majors and/or careers in engineering?
15. Do you feel prepared to provide guidance on students’ engineering career questions?
16. Are you able to help student differentiate between engineering disciplines?
17. What high school coursework would you recommend to a student who wants to be an engineer?
18. Does your district offer any engineering-specific course work for students?
   a. What is the typical profile of a student enrolled in a course like this?
Appendix C

Post-Professional Development Semi-Structured Interview Protocol

1. What aspects of the PD workshop did you find the most valuable or productive?
2. Do you have any suggestions for improving this workshop for the future?
3. How did your experience in this workshop influence your perception of the engineering design process?
4. How would you characterize the relationship between science and engineering?
5. Using your experience in the workshop, how do you envision the inclusion of the engineering design practices changing your science course?
6. Could you give one specific example of content in your science course that you plan to teach differently in the future by including engineering design?
7. Thinking of the example you just gave, describe your vision of this revised lesson or unit in your classroom. (What is your role in the lesson? What tasks are students engaged in?)
8. Remember that the engineering design process involves identifying and analyzing problems, developing solutions, and optimizing those solutions. Do you feel prepared to incorporate the engineering design practices into your science course curriculum?
   a. Yes: How did the workshop contribute to your confidence in teaching engineering?
   b. No: What areas of teaching engineering do you feel like you still need support with?
9. You had mentioned in our conversation before the workshop that you had hoped to be able to use engineering in your science course. What is your motivation for wanting to integrate engineering design practices with your science course content?
10. What obstacles do you anticipate as you begin (or continue) to integrate engineering content into your science course? How do you expect to overcome these obstacles?
11. Do you anticipate having support in your school for integrating engineering into your course? From whom? Do you feel you have access to the resources (financial, materials, instructional) you need?
12. From your perspective as a science teacher, what value do you see in infusing your science course content with the engineering design practices?
13. How do you expect your students will respond to the inclusion of engineering in your science course?
14. Do you feel prepared to provide students with guidance regarding engineering futures (college major, career)?
15. How have you shared your experience with your colleagues?
16. Can you compare this professional development experience to others you have participated in? Were there unique aspects of this experience? How did this influence your learning?
17. How did your interactions with your partner facilitate your learning? Would you expect your students to do the same?