A New Era of Science Education: Science Teachers' Perceptions and Classroom Practices of Science, Technology, Engineering, and Mathematics (STEM) Integration

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Dedication

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Abstract

Quality STEM education is the key in helping the United States maintain its lead in global competitiveness and in preparing for new economic and security challenges in the future. Policymakers and professional societies emphasize STEM education by legislating the addition of engineering standards to the existing science standards. On the other hand, the nature of the work of most STEM professionals requires people to actively apply STEM knowledge to make critical decisions. Therefore, using an integrated approach to teaching STEM in K–12 is expected. However, science teachers encounter numerous difficulties in adapting the new STEM integration reforms into their classrooms because of a lack of knowledge and experience. Therefore, high quality STEM integration professional development programs are an urgent necessity. In order to provide these high quality programs, it is important to understand teachers' perceptions and classroom practices regarding STEM integration.

A multiple-case study was conducted with five secondary school science teachers in order to gain a better understanding of teachers' perceptions and classroom practices in using STEM integration. This study addresses the following research questions: 1) What are secondary school science teachers' practices of STEM integration? 2) What are secondary science teachers' overall perceptions of STEM integration? and 3) What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices? This research aims to explore teachers' perceptions and classroom practices in order to set up the baseline for STEM integration and also to determine STEM integration professional development best practices in science education. Findings from the study provide critical data for making informed decision about the direction for STEM integration in science education in K–12.

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CHAPTER 1

Introduction

Rationale

In the executive report to President Barack Obama, *Prepare and Inspire: K–12 Education in Science, Technology, Engineering, and Math (STEM) Education for America's Future*, the President's Council of Advisors on Science and Technology stated that the education system in the U.S. must prepare students to have a strong foundation in science, technology, engineering, and mathematics (STEM) (President's Council of Advisors on Science and Technology, 2010). The report concluded that the progress and prosperity of the United States in the future will be dependent on the quality of K–12 STEM education. The congressionally requested report, *Rising above the Gathering Storm* (National Academic of Science, 2006) also raised the same concern. The report pointed out that within the U.S. there are not enough students graduating with STEM degrees to support the needs of the STEM workforce and that in the future there will not be enough qualified K–12 STEM teachers supporting STEM education. The report called for a comprehensive, coordinated federal effort to ensure that more students pursue STEM fields, as well as recommending the preparation of more qualified K–12 STEM teachers. Today, STEM education is a nationwide movement. Educators are mobilizing at both national and state levels to meet the call to increase students' interest and achievement in STEM fields. Unfortunately, policymakers, educators, and researchers do not have a common definition of STEM education and do not consistently agree or understand what STEM education should really be about in K–12 settings.

Currently in K–12 education, STEM disciplines such as science and mathematics are taught as isolated subjects in separate classrooms within schools. Although the subjects are taught separately, the actual nature of the work of most STEM professionals blurs the lines between disciplines. Judith Ramaley (2007), the former director of the National Science Foundation's education and human resources division, suggested that STEM education is an approach to engineering design and that science and mathematics subjects should be reformed by integrating engineering and technology into the regular curriculum to become a multidisciplinary teaching method. Teaching STEM disciplines through integration would be more in line with the nature of the work of STEM professionals.

Teaching integrated curriculum has many advantages. Curriculum integration is not a new idea in general (Furinghetti & Somaglia, 1998; Vars, 1991; Wraga, 1997). Integrating science and mathematics curriculum has been widely discussed by researchers and educators (Davison, Miller, & Metheny, 1995; Huntley, 1998; Lonning & DeFranco, 1997). For example, educators believed that integrating science and mathematics helps provide students with concrete examples of mathematics concepts and relevancy and that it motivates students to learn science and mathematics (Watanabe & Huntley, 1998). Other research studies suggested that solving engineering problems in science and math integrated curriculum improved students' learning in science and mathematics (Bottoms & Uhn, 2007; Schaefer, Sullivan, & Yowell, 2003). Also, adding technology into science and math could scientifically and mathematically enrich curriculum and instruction (The National Council of Teachers of Mathematics, 2000; National Research Council, 1996).

In summary, an integrated curriculum can provide learners with more consistent and relevant learning experiences, rather than fragmented concepts presented in single subject curricula (Clark & Clark, 1994; Frykholm & Glasson, 2005; Koirala & Bowman, 2003; McComas & Wang, 1998). Integrated curriculum, with its ability to incorporate information from different fields, has been shown to increase students' involvement, motivation, problem-solving skills, and cooperative learning skills (Childress, 1996; Niess, 2005; Ross & Hogaboam-Gray, 1998).

To begin to address the growing concerns about STEM education, many states, led by Massachusetts, Minnesota, Texas, and Oregon, have promoted STEM education through legislation mandating the addition of engineering standards to existing science standards (Kuenzi, Matthews & Mangan, 2006; Minnesota Academic standards: Science K–12, 2009; National Governors Association, 2007). For example, in 2009, in response to these national concerns, Minnesota added engineering concepts to the new K–12 science standards (Minnesota Academic Standards: Science K–12, 2009). The Nature of Science and Engineering standards clearly indicate that science and engineering "are not intended to be taught as a stand-alone unit or an isolated course, but embedded and used in the teaching, learning and assessment of the content in the other strands" (Minnesota Academic Standards: Science K–12, 2009, p. 1). In addition, *A framework for K–12 science education: Practice, crosscutting concepts, and core ideas* (National Academic of Science, 2011) also states that students need to understand and be interested in both science and engineering in order to make informed decisions when they encounter critical issues in our society. Spurred by policymakers and professional societies advocating for the inclusion of engineering, engineering is becoming a major focus in K–12 STEM education. Although both science and engineering play an essential role in K–12 STEM education, mathematics and technology should not be left out when talking about K–12 STEM education. Based on Tsupros, Kohler and Hallinen's (2009) idea, STEM education should be treated as an integration of science, technology, engineering, and mathematics in contexts that make connections between school, communities, and global enterprise for developing STEM literacy. A STEM curriculum should be guided by real-world problems that encourage students to actively apply STEM knowledge to design and conduct experiments, analyze and interpret data, and communicate within authentic situations (Sander, 2009; Smith & Karr-Kidwell, 2000; Wineburg & Grossman, 2000).

Although much research has been done to explore curriculum integration that emphasizes 2 or 3 of the 4 STEM subjects (Davison et al., 1995; Huntley, 1998; LaPorte & Mark, 1993; Lonning & DeFranco, 1997; Niess, 2005), it is not clear about how to integrate science, technology, engineering, and mathematics together. Furthermore, the few research studies that address K–12 STEM integration do not use a common definition of STEM integration. More research needs to be done on how K–12 STEM integration is conceptualized and how teachers implement STEM integration in K–12 classrooms (Dugger, 2011; Williams, 2011). The lack of a clear theoretical framework for STEM integration (Dugger, 2011; Williams, 2011), as well as information on what curriculum arrangements and classroom practices should be used (Venville, Wallace, Rennie, & Malone, 1999) needs urgent attention in K–12 STEM education.

Statement of the Problem

As the new science frameworks call for the integration of engineering concepts and technology under the umbrella of science standards in Minnesota, science teachers are confronted with the new challenge of implementing STEM integration in their classrooms. Since teaching STEM disciplines such as science and engineering has been considered an integrated approach, science teachers need to have content knowledge about all STEM subjects, as well as developing new teaching strategies, techniques, and skills to implement STEM integration in their classrooms.

Continuing professional development for science teachers to gain the necessary knowledge and experiences to teach STEM integration is considered a key reform strategy to address the problem in implementing STEM integration in science classrooms (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). Unfortunately, given the lack of agreed upon frameworks of STEM integration, models for quality STEM integration professional development programs have yet to be developed. As states prepare to invest considerable funds toward improving the quality of STEM education, it is imperative to explore science teachers' perceptions regarding STEM integration. In order to provide critical information to practitioners, administrators, researchers, and policymakers on how to conduct high quality STEM integration professional development programs, research on teachers' understanding, perceptions, and classroom practices about STEM integration is the essential first step in exploring the provision of the effective and best practices of STEM integration professional development in science education.

Goals and Objectives

This study explores teachers' perceptions of STEM integration and their STEM integration teaching practices. This research was conducted by using multiple-case design methodology. Five secondary science teachers participated in the study. The five teachers were recruited after they completed the STEM integration professional development program in 2009 (more details will be presented in Chapter 3).

To understand STEM integration, researchers and policymakers must explore teachers' current knowledge, perceptions, and classroom practices about STEM integration. The research questions that guide this study are as follows:

1. What are secondary science teachers' practices of STEM integration?
2. What are secondary science teachers' overall perceptions of STEM integration?
3. What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices?

Potential Significance of the Study

Today, the burgeoning STEM movement in K–12 education is at the national and state level. STEM integration has the potential to increase student interest in STEM subjects and, as a result, create new pathways into STEM fields. STEM disciplines are not intended to be taught as separate subjects in K–12 settings (Dugger, 2011; Ramaley, 2007). As many states start to emphasize STEM education, teachers struggle to teach STEM subjects with an integrated approach (Hargreaves & Moore, 2000). There is no doubt that there are many challenges to be conquered when teaching STEM disciplines by using integrated approaches. As the trend in recent national reports calls for increased attention on developing quality teachers in STEM fields (NAE, 2009; NAS, 2006) there is a great need to understand teachers' knowledge, perceptions, and classroom practices of implementing STEM integration. By understanding these factors, researchers and policymakers can design more effective pre- and in-service teacher education programs to better prepare teachers to teach using integrated approaches in the teaching of the STEM disciplines. This research provides critical data for making informed decisions about the direction for STEM professional development programs. The results also provide important information to practitioners, administrators, researchers, and policymakers on the role STEM should play in science education in the near future.

Summary and Overview of the Following Chapters

Chapter 2 provides an overview of the research literature related to the objectives of this study. Chapter 2 explores curriculum integration, K–12 STEM education, and teachers' perceptions and classroom practices of implementing curriculum integration. Chapter 3 provides details relating to research design, methodology, and study details such as descriptions of the participants and school settings, data collection, and data analysis. Chapter 3 also indicates the limitations of the study. Chapter 4 presents the individual cases for the teachers in this study. Chapter 4 is organized to present patterns and categories in each case. Chapter 5 explores the results of the cross-case analysis, presenting emergent themes to address each research question. Chapter 6 presents the discussions from this study as well as sharing implications for administrators, researchers, and policymakers related to the implementation of STEM integration in K–12 classrooms. In addition suggestions for future research efforts are shared.

CHAPTER 2

Review of the Literature

This chapter aims to provide a summary of the literature on topics relevant to this study: teachers' conceptualization and implementation of STEM integration. As STEM integration implies the integration of science, technology, engineering, and mathematics, it is important to understand the research on the model(s) of curriculum integration as well as the theoretical framework(s) of learning in curriculum integration. Thus, the first section of this chapter explores general frameworks and models for curriculum integration. The second section of this chapter examines the expectations surrounding integrating STEM disciplines and implementing K–12 STEM integration, particularly focusing on K–12 STEM curriculum integration. Finally, the last part of this chapter looks at teachers' general perceptions of curriculum integration and implementing STEM disciplines by using integrated approaches.

Curriculum Integration

The concept of curriculum integration is complex and challenging; curriculum integration is more than simply putting different subject areas together in the same lesson. The idea of curriculum integration derives from educators' awareness that in the real world, problems are not divided into separate disciplines (Beane, 1995; Czerniak, Weber, Sandmann, & Ahern, 1999; Jacobs, 1989). In approaching real-world problems and situations, people must apply concepts and skills that cut across the disciplines. Curriculum integration is an approach, or teaching strategy, that purposefully compiles knowledge, skills, and values from different subject areas to teach a concept in a more meaningful way.

However, researchers and educators cannot agree on a clear definition and conceptualization of curriculum integration (Czerniak et al., 1999; Huntley, 1998). The confusion in the literature about integrated curricula and the absence of a clear theoretical framework are problematic in developing a consistent theoretical and practical understanding of curriculum integration. For example, the terms “multidisciplinary” and “interdisciplinary” are frequently used in the literature to describe curriculum integration. Researchers attempt to distinguish between these two approaches by focusing on the paths and degree of integration. Lederman and Niess (1997) used the metaphor of chicken noodle soup versus tomato soup to explain the fundamental differences between multidisciplinary and interdisciplinary. In their description, multidisciplinary approaches were characterized as a bowl of chicken noodle soup, where each ingredient maintained its identity within a heterogeneous mixture. On the other hand, tomato soup represented interdisciplinary approaches, in which all ingredients/subjects were mixed together and could not be distinguished apart from one another—a homogeneous mixture.

Drake (1991, 1998) also described curriculum integration through multidisciplinary, interdisciplinary and transdisciplinary approaches. He suggested that in a multidisciplinary approach students are expected to make the connections among subject areas through a theme or issue that had been taught in different classrooms at the same time. In an interdisciplinary approach the subjects are interconnected beyond a theme or issue, cut across subject areas, and focus on interdisciplinary content and skills.

An example for interdisciplinary approach is that if students were asked to create a solar-powered boat, they would be expected to apply their knowledge from different subject areas, such as using science and math, to explore the concepts of sinking, floating, and stability in order to design their boat hulls. In a transdisciplinary approach, the focus is on real-life issues, not different subject areas. The goal for transdisciplinary study is to provide students with a broad view of how a real-life issue interacts with disciplines and how that affects a human's life. For example, with the topic of global warming, students are expected to connect this issue to many different factors, including social, political, economic, international, and environmental concerns. However, as Drake (1998) suggested, "One position is not superior to another: rather, different approaches are more appropriate than others according to the context in which they are used (p. 19)." It is very likely that, depending on the situation, practitioners use different curriculum integration approaches to fit their needs.

In addition to multidisciplinary, interdisciplinary, and transdisciplinary approaches, some researchers use teaching practices to categorize different models of curriculum integration. For example, Fogarty (1991) categorized a continuum of integration using 10 models: the fragmented, connected, nested, sequenced, shared, webbed, threaded, integrated, immersed, and networked models. The models begin with efforts that attempt to integrate curriculum within single disciplines (the fragmented, connected and nested models) to efforts across several disciplines (the sequenced, shared, webbed, threaded, and integrated models) and then to efforts that intensely address personal interests (the immersed and networked models). The fragmented model focuses directly on one major academic area such as mathematics or science at a time. Students move from one classroom to another and the subjects are taught by different teachers. The fragment model, therefore, left students with a fragmented view of the curriculum. The connected model makes explicit connections with each subject area being taught and connects one topic or one skill. The idea of the connected model is that teachers should make the connection rather than assume that students automatically understand the connection. For example, in a connected approach, a mathematics teacher relates the concepts of converting fractions to decimals when she teaches fractions. The nested model emphasizes integrating multiple skills, such as a thinking skill, a social skill, and a mathematics skill, that take place in each subject area. In the fragmented, connected and nested models, as Fogarty suggested, the integration happens within single disciplines. However, the key in distinguishing these three models depends on how many concepts or skills a teacher purposefully wants to integrate.

In the sequenced model, the topic or unit is purposefully arranged to coincide with one another. Although the topic or unit is taught in different classrooms, the sequenced model aims to strategically arrange curriculum to provide a broad view that relates concepts. For example, a lesson on food chains could be followed by a unit on energy to build on the food chain knowledge and tie the content knowledge together. The shared model puts two disciplines into one focus. This model also focuses on concepts and skills development. For example, a science teacher and a mathematics teacher may teach content and skills by using data collection and graphing as shared concepts that overlap in both science and mathematics. The webbed model attempts to use a theme to web different disciplines together. A similar conceptual theme is used to provide a fertile ground for cross-discipline units. For example, the theme of Inventions can lead to the study of simple machines in science, reading and writing about inventors in the language arts, and industrial revolution in history. As for the threaded model, Fogarty suggested that the threaded model "supersedes all subject matter content (pp.64)" to focus on different skills, such as thinking skills, study skills, technology skills, mathematics skills, and so forth that need to be learned. She suggested, for example, a teacher can ask students, "What thinking skill did you find most helpful?" and "How can you communicate with your group in a better way to complete the task?" in the threaded model. Like the shared model, the integrated model emphasizes overlapping concepts and skills in different disciplines. However, the integrated model needs to integrate more than 3 disciplines rather than just 2. Therefore, the quantity of disciplines that are integrated determines if a model should be categorized as shared or integrated. Fogarty's last two models, the immersed and networked models, suggest that learners play a critical role in integration. These two models suggest that only the learners themselves can direct the integration process, because the integration process is highly associated with learners' interests, expertise, and experiences. For example, Fogarty suggested a student who is in love with butterflies may conduct an experiment to understand how temperature has influenced the life cycle of a butterfly. The student's internal integration of knowledge and information, such as combining biology and technology, was based on personal interests and needs. In summary, Fogarty uses the following criteria to distinguish her 10 curriculum integration models: where integration occurs (within single disciplines or cross-disciplines), the specific concepts and skills that are intended to be taught, the number of disciplines that should be integrated, and the role a student plays in an integrated curriculum.

As stated above, Drake (1991, 1998) researched the idea of curriculum integration through multidisciplinary, interdisciplinary, and transdisciplinary approaches. His idea of a multidisciplinary approach had very similar concepts to Fogarty's webbed and sequenced model, which stated that curriculum integration should happen either by rearranging the curriculum or by using a theme to make connections among different disciplines. An interdisciplinary approach corresponded with the connected, nested, shared, threaded, and integrated models that emphasized concepts and skills practices in an integrated curriculum. As for the immersed and network models, which use real-life issues that address personal experiences and interests, a transdisciplinary approach could be a possible match with these two models (Tables 1 and 2).

Table 1

Summary of Curriculum Integration Models (Lederman, Niess, & Drake)

Models	Ideas of curriculum integration	Important elements of curriculum integration	Concepts to distinguish different models of curriculum integration
Lederman & Niess (1997)	Multidisciplinary and interdisciplinary	• Multidisciplinary: Each discipline could be identified in curriculum integration. • Interdisciplinary: Each discipline could not be distinguished from one another	A heterogeneous mixture or a homogeneous mixture
Drake (1991, 1998)	Multidisciplinary, interdisciplinary and transdisciplinary	• Multidisciplinary: Using a theme or issues to connect among subject areas in different classrooms • Interdisciplinary: Focusing on interdisciplinary content and skills that go beyond a theme or issues in one classroom • Transdisciplinary: Using real-life issues to connect social, political, economic, international, and environmental concerns	The purpose of a theme or issue that is used in curriculum integration, and if the integrated curriculum is implemented in one or in different classrooms

Table 2

Summary of curriculum integration models (Fogarty)

Models	Ideas of curriculum integration	Important elements of curriculum integration	Concepts to distinguish different models of curriculum integration
Fogarty (1991)	Fragmented, connected, nested, sequenced, shared, webbed, threaded, integrated, immersed, and networked models	• Fragmented model: Within a single discipline • Connected model: Focuses on one skill or one concept within a single discipline • Nested model: Focuses on multiple skills within a single discipline • Sequenced model: Cross-discipline and focuses on the arrangement of curriculum to make connections • Shared model: Two disciplines merged into one focus, such as content knowledge or skills development • Webbed model: A theme or an issue that is used to connect cross-discipline units • Threaded model: Focuses on different skills that are cross-disciplines • Integrated model: Focuses on overlapping content knowledge and skills development for more than two disciplines • Immersed model: Different disciplines distinguished by learners that are used to address learners' interests • Networked model: Different disciplines used without boundaries to address learners' interests	The 10 models are distinguished by where the integration occurred (within single disciplines or cross-disciplines), the specific concepts and skills that are intended to be taught, the number of disciplines that are integrated, and the role a student plays in an integrated curriculum.

Fogarty's immersed and networked models suggested personal ownership as an important focus in curriculum integration. Similarly, Beane (1991) stated that curriculum integration needs to address real-life questions which are based on personal interests and experiences. Beane believed that genuine learning occurred when students could transfer their learning experience to something meaningful to them. According to Beane, meaningful learning cannot be separated from real-world contexts and personal experiences. Similarly, Brooks, and Brooks (1993) stated that meaningful learning occurs when learners make connections between prior knowledge and new experiences and skills within real-world contexts. Hirst (1974) pointed out that the separation of subject areas restricts learning by alienating learners from real-world experiences. Advocates of curriculum integration suggest that curriculum integration provides students more meaningful learning experiences by connecting disciplinary knowledge with personal and real-world experience (Beane, 1991, 1995; Burrows, Ginn, Love, & Williams, 1989; Capraro & Slough, 2008; Childress, 1996; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). Therefore, an integrated curriculum should naturally create an environment that helps learners to apply knowledge in a new situation.

Another critical aspect of curriculum integration is that it is defined as "wholeness and unity," rather than as "separation and fragmentation" (Beane, 1991, p.9). Several studies (Tsupros et al., 2009; Venville et al., 1998, 2000), as well as Fogarty's webbed model, suggest that an integrated curriculum which contains problem-based projects or issues is the most promising approach in blurring subject boundaries. An integrated curriculum should help students see the relevancy of how different subjects are tied together and how they build on one another. Integration as a curriculum design requires that teachers organize curriculum around problems and issues that are of personal and social significance in the real world. Simply put, curriculum integration involves real-world applications to develop the process of real-world problem solving.

K–12 STEM Integration

The first part of this section explores research on science and math curriculum integration while recognizing that teaching science and mathematics have a varying degree of overlap. Science and mathematics highly connect with each other. For example, mathematics skills such as graphing play a very important role in allowing students to present their science data. Integrating science and mathematics in K–12 education has been considered as a mechanism to make science and mathematics more meaningful to students for a very long time (Davison et al., 1995). The purpose here is to draw on the historical literature base of science and mathematics integration to develop a theoretical framework for integrating science and mathematics in ways that may also be a good fit for STEM integration in K–12 education. The second part of this section focuses on the connections among mathematics, science, and technology (MST). Following a research review of mathematics, science, and technology integration, the section then shifts to the addition of the fourth element of STEM; engineering, which only recently has been considered an important discipline that should be integrated into science education (Kuenzi et al., 2006; Minnesota Academic standards: Science K–12, 2009; National Academic of Science, 2006; National Governors Association, 2007). Therefore, in this part, the literature review focuses on how engineering is/should be integrated in K–12 science classrooms. Overall, this section aims to explore the meaning of STEM education and STEM integration in K–12 education from the limited research studies.

K–12 Science and Mathematics Integration

Just as there is a no general consensus on the nature of curriculum integration, there is also no generalized consensus about the usefulness of integrated science and mathematics (Berlin, 1991). Davison et al. (1995) recommended several ways that science and mathematics instruction could be integrated. These authors believe science and mathematics should be integrated in ways that make mathematics and science relevant and meaningful to students. They suggested five types of science and mathematics integration: discipline specific, content, process, methodological, and thematic. Discipline specific integration focuses attention on specific subdisciplines of mathematics or science, such as algebra and geometry in mathematics and biology and physics in science. It seemed Davison et al. believed as long as a teacher integrated different subdisciplines within single disciplines regardless the content, concepts, skills and procedures, it was discipline specific integration. This view corresponded with Fogarty's fragmented, connected, and nested models. Content specific integration focused on topics, such as speed in science and measurement in mathematics. In a content specific integration, a teacher purposefully aligned the content to infuse the objectives from both mathematics and science. Davison et al. suggested, for example, if the science content objective is the study of dinosaurs and the content objective for mathematics is measurement, a teacher could integrate these two content objectives by creating a life-size dinosaur. Process integration focused particularly on the scientific and mathematical process. For example, Davison et al. defined observing, predicting, and controlling variables as scientific process skills.

Reasoning and problem solving were mathematical process skills, and communication was overlapped between scientific and mathematical process skills. These were the skills that should be considered as the primary learning goals when implementing process integration. An example of process integration may involve asking students to make a prediction about polar bear population size based on the weather model in the Arctic. This involves predicting, which is the skills that teachers want to emphasize in process integration. Furthermore, methodological integration looked at how people learn science and math in order to develop an activity that addresses science and mathematics teaching and learning methods such as inquiry-based teaching or experiential learning. The final type of integration was thematic integration. The thematic integration approach starts with solving a problem or an issue as a way of connecting multiple disciplines.

Berlin and White (1995) constructed their ideas of mathematics and science integration based on their early work, Berlin-White Integrated Science and Mathematics (BWISM) Models (1994). The following six aspects were discussed in their ideas of mathematics and science integration: 1) learning, 2) ways of knowing, 3) process and thinking skills, 4) conceptual knowledge, 5) attitudes and perceptions, and 6) teaching. Depending on different needs, teachers could integrate mathematics and science from very specific scientific and mathematical concepts (such as balance and matter in science and ratios and fractions in math), with process and thinking skills (such as observing and inferring in science and reasoning and problem solving in mathematics), to overlap conceptual knowledge both in science and mathematics (such as measuring patterns and relationships), to promote scientific and mathematical learning attitudes (such as being skeptical and accepting ambiguity), and to teaching strategies that teachers used to help students develop scientific and mathematical literacy (such as inquiry-based teaching and student-centered learning). Berlin and White's (1995) ideas were quite similar to those of Davison and his colleagues (1995) view of integrating mathematics and science. Content, process and thinking skills, and methodological integration (teaching strategies) were the three themes that overlapped in the integration models of Berlin and White, and Davison et al.

Huntley (1998) built a theoretical framework for science and mathematics integration by using the following three terms: *intradisciplinary*, *interdisciplinary*, and *integrated*. Huntley suggested that intradisciplinary curriculum focused on only one discipline. In an intradisciplinary approach there was no other discipline involved besides the one that teachers exclusively wanted to focus on. On the other hand, an interdisciplinary approach involved one major discipline and one or more other disciplines to support the major discipline. Huntley explained this interdisciplinary approach by using the notion of "foreground/background—that discipline that is to be mastered is foreground, and the discipline used to establish relevance or context is background (pp. 321)." An example of an interdisciplinary approach is asking students to apply their mathematics skills to create a graph to explain the relationship between volume and weight. In this example, the relationship between volume and weight is the foreground and the mathematics skills that are used to create a graph are the background. Huntley believed that the idea of implicitly or explicitly integrating disciplines was an important thought to distinguish an integrated approach from an interdisciplinary approach. Interdisciplinary approaches implicitly connect between/among disciplines. However, in an integrated curriculum, teachers needed to explicitly make connections between/among disciplines by giving equal attention to two (or more) disciplines. For example, in an integrated curriculum, students needed to see the relationship between science and mathematics. Huntley used an example of determining the amount of energy that would be produced by calculating the surface area of a leaf to explain the idea of integrated discipline. She noted that this activity helped students to not only use their mathematics skills (calculating surface area for an irregularly shaped object) in a new situation, but also to learn the relationship between the surface area of a leaf and photosynthesis. Furthermore, the activity also asked students to use what they have learned to determine what would happen to a human's life if all rainforests disappeared. Therefore, the activity also could generate a whole new meaning of a leaf, photosynthesis, energy, and humans' lives to students. Huntley created her framework by combining her idea of science and mathematics integration with the Education Development Center's (1969) five integration models of mathematics and science: 1) mathematics for the sake of mathematics, 2) mathematics for the sake of science, 3) mathematics and science, 4) science for the sake of mathematics, and 5) science for the sake of science (Fig. 1).

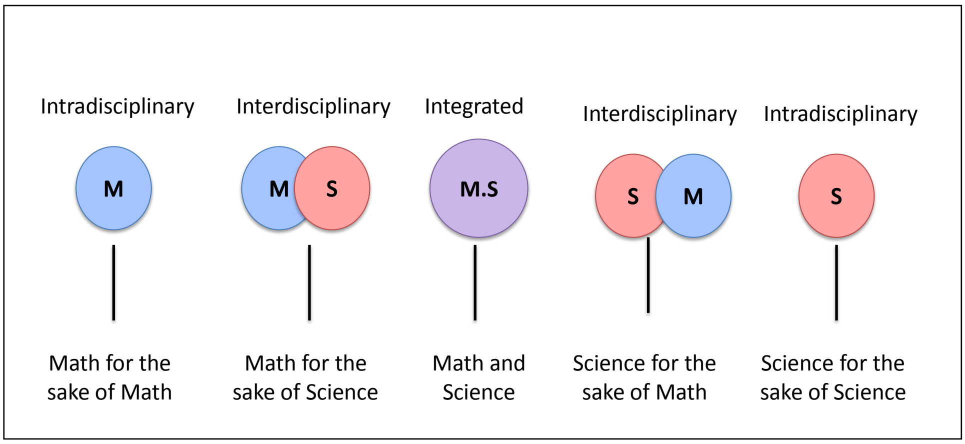

Figure 1. Huntley's Framework of Mathematics and Science Integration (modified from Huntley [1998].)

Some important concepts need to be addressed after summarizing curriculum integration and K–12 science and mathematics integration (Table 3). First, one of the important features which many researchers use to distinguish different types of curriculum integration is within or cross-disciplines (Drake, 1991, 1998; Davison et al., 1995; Fogarty, 1991; Huntley, 1998). Second, overall content/concepts and process/skills are very important in curriculum integration regardless if they are within or cross-disciplines. However, some research particularly emphasizes the learning process/skills rather than content/concept delivery. Some of examples of this are Fogarty's (1991) nested and threaded models; Davison et al.'s (1995) process integration approach; and Berlin and Whites' (1995) idea about process and thinking skills integration. Third, using problem-based projects or issues stands out as one of the critical elements in integrated curriculum. Some research specifically states that curriculum integration needs to use real-life problems or issues that address personal interests and experiences (Beane, 1991, 1995; Burrows et al., 1989; Capraro & Slough, 2008; Childress, 1996; Fogarty, 1991; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). However, other studies do not mention addressing personal interests and experiences, but rather suggest using a problem or issue as a theme which acts as context to connect different disciplines (Drake, 1991, 1998; Davison et al., 1995; Fogarty, 1991; Huntley, 1998). Finally, teaching strategies, such as teaching and student-centered learning, cooperative learning, or experiential learning, could be major foci when using the curriculum integration approach.

Table 3

The Focus of Curriculum Integration

Focus of curriculum integration	Models that support the ideas
Within a single discipline or cross-discipline integration	Drake, 1991, 1998; Davison, Miller, & Metheny, 1995; Fogarty, 1991; Huntley, 1998.
Content/concept specific	Interdisciplinary (Drake, 1991, 1998); Connected, Shared and integrated models (Fogarty, 1991); Content specific approach (Davison, Miller, & Metheny, 1995); (Berlin and White, 1995).
Process/skills specific	Interdisciplinary (Drake, 1991, 1998); Connected, Nested, Shared, Threaded, Integrated models (Fogarty, 1991); Process integration approach (Davison, Miller, & Metheny, 1995), (Berlin and White, 1995.)
A theme, such as a problem or an issue, to connect disciplines	Transdisciplinary (Drake, 1991, 1998); Webbed model (Fogarty, 1991); Thematic integration approach (Davison, Miller, & Metheny, 1995); Huntley, 1998.
A real-life problem/issue that addresses personal interests	Immersed and networked models (Fogarty, 1991); Meaningful learning (Beane, 1991, 1995 and others).
Teaching strategies that help students to learn	Methodological integration (Davison, Miller, & Metheny, 1995); Berlin and White, 1995.

Mathematics, Science and Technology (MST) Integration

For the past 3 decades, technology has been considered one of the necessary disciplines to integrate science and mathematics (Childress, 1996; Foster, 1994; International Technology Education Association, 1996). The International Technology Education Association (ITEA) heavily advocates mathematics, science, and technology (MST) integration. ITEA (1996) suggested that technologically literate persons “are capable problem solvers who consider technological issues from different points of view and in relation to a variety of contexts…” and “incorporate various characteristics from engineers, artists, designers, craftspeople, technicians, mechanics, and sociologists that are interwoven and act synergistically (ITEA, 1996, p. 11).

Childress (1996) provided an example of how to integrate technology from the *Technology, Science, Mathematics (TSM) Integration Project*, which was supported by the National Science Foundation. The example was to challenge students to “design and build a device that efficiently transforms wind energy into electrical energy.” The framework of the TSM project was to apply science and mathematics knowledge to solve a technological problem. The devices that students created were technological, and they also used different technologies as tools to create their devices. While students designed their devices to efficiently transform wind energy, Childress also asked them to record step by step the process of how they designed and created their devices. The project not only asked students to create a device, but also to focus on their thinking processes while they created their devices. Problem solving processes were purposefully included as a critical element in this TSM activity. An important point from Childress' TSM example was that technology was treated in a way that was very similar to engineering in K–12 education, which considers problem solving by using the design process as an important learning objective in the project. Therefore, just as in the real world, there was no clear distinction between engineering and technology in Childress' example.

On the other hand, MST integration is not only an integrative approach to solve a technological problem by using science and math, but also shows a need to be aware of the cultural, social, economic, and political effects of technology (Foster, 1994; Savage & Sterry, 1990). Students were expected to increase their scientific, mathematical, and technological understanding which, as a result, could help them to make informed decisions and participate in civic and cultural affairs and economic productivities (National Academy of Science: Successful K–12 STEM Education, 2011). Therefore, another goal of MST integration is to increase STEM literacy.

In summary, technology can be seen as a tool or a process to solve a problem in mathematics, science, and technology integration with an emphasis on social, economic, and political issues. Technology also can be seen as a creation as the end goal of a lesson. The focuses of integrating technology were similar to the ways of integrating engineering as discussed in the following section on engineering integration.

Engineering in K–12 Education

Spurred by specific attentions to STEM education from professional societies such as the National Science Foundation, National Research Council, and National Academy of Science, engineering has now been added into many state science standards, such as Minnesota, Oregon, and Massachusetts. The report, *Engineering in K–12 Education*, recently released by the National Academy of Engineering and the National Research Council (Katehi, Pearson, & Feder, 2009), provided a very insightful view of engineering education in K–12 schools. Based on the report, which reviewed 34 engineering programs, engineering was embedded and interwoven in science, math, and technology. The report described three main principles for K–12 engineering education. First, the report found that K–12 engineering education should emphasize engineering design. Second, K–12 engineering should incorporate important science, mathematics, and technology concepts and skills. Finally, K–12 engineering should align with 1) systems thinking, 2) creativity, 3) optimism, 4) collaboration, 5) communication, and 6) attention to ethical considerations to promote engineering "habits of mind" (pp. 4–6). In summary, the report also concluded that there is no widespread agreement on what should be taught in K–12 engineering. However, it pointed out that the key engineering ideas that have been used in K–12 classrooms are engineering design, constraints, modeling, optimization, trade-offs, and systems.

Furthermore, many research studies suggest that engineering design projects require an interdisciplinary approach that incorporates knowledge from science, mathematics, and technology (Brophy, Klein, Portsmore, & Rogers, 2008; Douglas, Iversen, & Kalyandurg, 2004; Thornburg, 2009), as well as skills related to problem solving, creative thinking, and communication (Erwin, 1998; Katehi et al., 2009; Lewis, 2006; Roth, 2001; Thornburg, 2009). The existing research also suggests that integrating engineering into science and mathematics classrooms might benefit students' learning in science and mathematics (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Katehi et al., 2009).

Engineering design is a common feature of all of the reports and studies related to K–12 engineering education. For example, Katehi et al. (2009) suggest that the first principle to be included in teaching engineering in K–12 classrooms is engineering design. Engineering design is the process engineers use to solve engineering problems and to develop products. It also encapsulates the essence of the engineering profession. In 1958, Ver Planck, in the report *Task Force on Engineering Analysis and Design*, described engineering design as using creativity and imagination to search for solutions. Peterson (1990) suggested that engineering design is “almost invariably multidisciplinary (p.531).” According to the 2011–2012 Criteria for Accrediting Engineering Programs (ABET, 2010), the Accreditation Board for Engineering and Technology (ABET) defined engineering design as “the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering science are applied to convert resources optimally to meet these stated needs (p.2).”

Although there are many models of the engineering design process, they all have very similar steps. For example, the Engineering is Elementary (EiE) curricula developed by the Museum of Science–Boston, feature lessons and learning activities for elementary students that use five steps of the engineering design cycle: ask, imagine, plan, create, and improve. An example for secondary education is the *Power of the Wind: How can we think like an engineer* program by the University of Illinois. The engineering design cycle has eight steps: 1) What is the challenge? 2) How have others solved this? 3) Brainstorm possible solutions: What are the design criteria and constraints? 4) Which of the possible solutions do you choose? 5) Build prototype. 6) How does it work? Try it and test again. 7) How do you learn from the design of others? and 8) How can you use your new ideas to improve your design? Despite the fact that the engineering design model has many variations, they all have very basic and similar processes, which cycle among identification of the problem, creative thought, analysis, and decision making. In summary, according to the existing research in this section, engineering design has been treated as a pedagogical strategy to bridge science and mathematics concepts to solve open-ended problems, develop creative thinking, formulate solutions and make decisions, and consider alternative solutions to meet a variety of constraints.

Teachers' Perceptions and Practices of STEM Interactions

Teachers' beliefs could be defined as the way they conceptualize their work through their mediations and/or interventions that happen in the classroom in relation to student learning (Richards, Gallo & Renandya, 1999). Teachers' beliefs and their practices are interactive, complex, and context dependent (Mansour, 2009). Previous studies argued that teachers' beliefs and attitudes influence their classroom practices in mathematics and science (Calderhead, 1996; Handal & Herrington, 2003; Levitt, 2002; Roehrig & Luft, 2004; Stipek, Givvin, Salmon, & MacGyvers, 2001; Wilkins &

Ma, 2003). Teachers' beliefs stem from their own experiences and their educational environments (Tasai, 2002). For example, if a teacher was taught in a very teacher-centric way when she/he was growing up, the teacher tended to believe that a teacher-centered approach is the best way to teach her/his students. Oliver and Koballa (1992) found that science teachers' beliefs highly relate to knowledge, attitudes and behavior, personal experience, and beliefs of acceptance or rejection of a proposition. Teachers' beliefs and personal experiences also create a subjective view that influences their beliefs concerning what constitutes an effective and efficient learning environment (Mansour, 2009). Therefore, whether or not teachers have positive beliefs toward new teaching approaches is one of the critical factors that affect their acceptance and willingness to implement new teaching ideas into their classroom practices.

Teachers' beliefs also influence their expectations of how their teaching can effectively help students learn (Bell & Gilbert, 1996; Benner & Mistry, 2007). For example, Bell and Gilbert (1996) suggested that science teachers are more likely to mix features of science teaching methods, such as using teacher-directed teaching strategies as well as cooperative learning and inquiry-based learning strategies.

However, very little research has explored how teachers' beliefs influence the use of STEM integration in their teaching. Some research studies aimed at understanding teachers' beliefs, attitudes, and expectations about using an integrated curriculum. In order to use an integrated curriculum, teachers need to have a strong belief and positive attitudes that students learn best when the curriculum is integrated (Hargreaves & Moore, 2000; Huntley, 1998). Mathison and Freeman (1997) identified six categories where teachers' beliefs related to curriculum integration by analyzing existing research studies. They pointed out that teachers believed curriculum integration could: 1) improve and create more meaningful relationships with students, 2) provide more flexibility and less schedule and subject fragmentation, 3) increase time efficiency, 4) create better understanding between/among disciplines by collaborating with other teachers, 5) support human brain development and learning processes, and 6) fulfill the needs of the 21st century and national standards. Teachers also believe curriculum integration helps students to connect school learning with their personal lives and future work (Hargreaves & Moore, 2000; Mathison & Freeman, 1997; Schlechty, 1990).

Research studies provide evidence that teachers' beliefs, attitudes, and expectations toward engineering education relate to their decision to integrate engineering contexts or contents into their instruction practices (Nathan, Tran, Atwood, Prevost, & Phelps, 2010). In other words, teachers' beliefs about integrating engineering into science and math are strongly related to whether they believe STEM disciplines can be successfully implemented in a classroom. Although many authors have discussed the importance of integrating engineering into the K–12 curriculum (National Academy of Engineering, 2009; National Academy of Science: Successful K–12 STEM Education 2011; National Governors Association, 2007) little research has focused on teachers' attitudes toward the integration of engineering into their teaching. Douglas et al. (2004) conducted a study that specifically sought to understand teachers' thoughts of engineering as an academic and career pathway for their students. In the 522 total responses from K–12 teachers, the study found that teachers believed teaching engineering could be a way to help teach students about business and history. However, there was no evidence in the study to support that teaching engineering could help teach subjects other than business and history. Although science and mathematics teachers believe that science, mathematics, and engineering are related in a very natural way (Wang, Moore, Roehrig, & Park, 2011), and that engineering education can provide many benefits to students (Douglas et al., 2004), they also believe that engineering is not accessible to a large number of their students, particularly girls and minorities (Douglas et al., 2004).

Summary of Chapter 2

Chapter 2 reviewed research to provide a discussion that related to curriculum integration in general, K–12 STEM integration, and teachers' perceptions and practices of curriculum/STEM integration. Chapter 2 also discovered the lack of literature describing STEM integration in K–12, frameworks for K–12 STEM integration, and teachers' beliefs and classroom practices of STEM integration from existing research studies. The next chapter will focus on the theoretical and methodological approach used to design the study and collect and analyze data.

CHAPTER 3

Research Design and Methods

Chapter 3 aims to provide detailed information about the research design, methodology and overall methods that are used to answer the research questions:

1. What are secondary science teachers' practices of STEM integration?
2. What are secondary science teachers' overall perceptions of STEM integration?
3. What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices?

Chapter 3 is divided into four sections. The first section provides a description of the Minnesota Nature of Science and Engineering standards as these standards provide the context in which these teachers are expected to operate. The second section explains why case study is the most suitable methodology for this study. The third section of this chapter provides detailed information about 1) the STEM integration professional development program experienced by the research participants, 2) participants and school settings, 3) data collection, 4) data analysis and 5) plans for reliability. Finally, the last section in this chapter discusses the limitations of the study.

The Nature of Science and Engineering Standards

In 2009, Minnesota added engineering concepts to the new K–12 science standards. The introduction to the Minnesota standards states, “It is important to note that the content and skills in The Nature of Science and Engineering are not intended to be taught as a stand-alone unit or an isolated course, but embedded and used in the teaching, learning and assessment of the content in the other strands” (Minnesota Academic standards: Science K–12, 2009). However, the standards separate out content into four strands (Earth and Space Science, Physical Science, Life Science and Nature of Science and Engineering) with the specific benchmarks and standards related to the practice of engineering being separated from the content standards.

Within the Nature of Science and Engineering strand, there are three substrands, each of which is subdivided further into benchmarks and standards: the practices of science; the practices of engineering; and interactions among science, technology, engineering, mathematics, and society. Under the substrand of the practice of science, for example, a ninth grader should be aware that “scientific inquiry uses multiple interrelated processes to investigate and explain the natural world (p.28).” According to the substrand of the practice of engineering, the ninth grader needs to understand that “engineering design is an analytical and creative process of devising a solution to meet a need or solve a specific problem (p. 29).” As for the substrand of interactions among science, technology, engineering, mathematics, and society, the student should recognize that “science, technology, engineering and mathematics rely on each other to enhance knowledge and understanding (p. 30).” Table 4 showed an example of the expectations of the standards that a high school student should achieve in science in Minnesota.

Table 4

Example of Substrands and Standards within the Minnesota Nature of Science and Engineering Strands for High Schools

Substrand	Standards	Benchmark
The Practice of Science	Scientific inquiry uses multiple interrelated processes to investigate and explain the natural world.	Identify the critical assumptions and logic used in a line of reasoning to judge the validity of a claim.
The Practice of Engineering	Engineering design is an analytical and creative process of devising a solution to meet a need or solve a specific problem.	Identify a problem and the associated constraints on possible design solutions.
Interactions Among Science, Technology, Engineering, Mathematics and Society	Science and engineering operate in the context of society and both influence and are influenced by this context.	Communicate, justify and defend the procedures and results of a scientific inquiry or engineering design project using verbal, graphic, quantitative, virtual or written means.

Although the standards do not have substrands that specifically address the practice of mathematics and technology, they do require students to be able to make a connection among all STEM disciplines. For example, two of the benchmarks, which fall under the substrand of interactions among science, technology, engineering, mathematics and society, require a ninth grader to be able to "describe how technological problems and advances often create a demand for new scientific knowledge, improved mathematics and new technologies (p. 30)," and to "analyze the strengths and limitations of physical, conceptual, mathematical and computer models used by scientists and engineers" (p. 30).

Methodology: Case Study

This study is a multiple case study (Yin, 2003) that aims to depict the complex phenomena of teachers' perceptions and classroom practices of STEM integration. Case study research, like other forms of qualitative research, is a form of interpretive research (Merriam, 1998; Stake, 1995). Qualitative methods, in general, provide a place for research participants explicitly to have their voices heard and for researchers to build theories.

Case study has been preferred to other methods when researchers have little control over the events, and when the research is an attempt to understand a particular phenomenon in a real-world context (Yin, 2003). Yin (2003) defined a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 13). This process facilitates answers to inquiries of meaning around experience, providing an understanding of a particular subject. Case study has the ability to bring deep understanding of a case, and to provide intrinsic knowledge and details regarding a problem or issues of interest to a researcher (Stake, 1995).

Multiple case study design suits this study due to the nature of the research questions. Using multiple case study research is necessary in order to explain and describe whether the teachers' perceptions about STEM integration aligned with their teaching practices as well as the factors that affected that relationship when teachers implement STEM integration. This study makes purposeful attempts to explore teachers' perceptions and classroom practices about STEM integration by carefully studying five science teachers who have participated in a STEM integration professional development program and have implemented a STEM integration unit. Additionally, the study aims to explain how teachers' perceptions of STEM integration are connected with their classroom practices. Pattern matching within multiple cases, where cases may be related to some theoretical proposition (Campbell, 1975), was very useful in providing an opportunity for a rich set of data for building a theory. For these reasons, a multiple case study is the most appropriate methodology.

Method

This section of the chapter provides details related to the design of this research study. The section is divided into five subsections providing details on the1) STEM integration professional development program, 2) participants and school settings, 3) data collection, 4) data analysis, and 5) plans for reliability.

STEM Integration Professional Development Program

The *Secondary STEM Integration* teacher professional development (PD) program provided background and experiences in STEM integration for science and mathematics teachers in grades 6–12. The PD program sought to help science and mathematics teachers gain familiarity with the new Minnesota Nature of Science and Engineering standards and associated mathematics standards and to encourage the incorporation of engineering into their science and mathematics teaching. The training provided instructional strategies to aid secondary school teachers in implementing STEM integration in their classrooms and increasing their understanding of the connection between the various STEM areas. All five teachers in this study participated in this PD.

The overall goal of the STEM integration professional development program was to develop teachers' deeper understanding of the subjects they teach and to explore mechanisms for integration across the STEM disciplines. The professional development program included 5 days of training spread throughout the 2009–2010 academic year (Table 5), along with Professional Learning Community (PLC) sessions between each training day. The PLC activities were highly structured and closely tied to the training days of the module. They were designed for teachers to meet with each other and reflect on what they learned during the professional development sessions and to share their experiences when they implemented what they had learned from the PD into their classrooms. The PD was designed based on a broad selection of references, such as the Accreditation Board of Engineering and Technology. For example, the Accreditation Board for Engineering and Technology (ABET, 2010) defined engineering design as "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering science are applied to convert resources optimally to meet these stated needs" (p.2). Therefore, the PD topics included: (1) exploring engineering as a discipline and the engineering design cycle, (2) exploring mathematical and science connections to engineering design cycles lessons, (3) exploring mathematical thinking through Model-Eliciting Activities (Lesh & Doerr, 2003), (4) technology integration to enhance learning of science, engineering, and mathematics, and (5) orchestrating student discussions around STEM concepts (see Table 5 for more detailed information about each training day). The facilitators who delivered the PD were professors and graduate students from a research-intensive university in the Midwest, both in STEM education and STEM fields. The facilitators focused on providing direct STEM integration learning experiences and sample activities that could be used by teachers in their classrooms.

The STEM integration professional development program highlighted the nature of the disciplines of STEM as well as the integration of the disciplines. The PD examined engineering through the lens of design, taking the view that engineering practice, at its core, is a way of thinking in order to solve problems for a purpose (ABET, 2010). Engineering design was presented in multiple forms but always highlighted the fact that it is the "distinguishing mark of the engineering profession" (Dym, 1999). The PD also focused on two common definitions of technology. In the more inclusive view, technology is defined as the process by which humans modify their surroundings to fit their needs and desires (International Technology Education Association, 2000). The second definition focuses on artifacts of technology:

computers, medicine, wind turbines, etc. Pearson and Young (2002) state that technology "includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts ... The knowledge and processes used to create and to operate technological artifacts—engineering know-how, manufacturing expertise, and various technical skills—are equally important parts of technology" (p. 13). Real-world problems often employ technologies and creation or modification of technologies can provide solutions to problems. The PD considered technology as the process by which humans modify their surroundings to fit their needs and desires and artifacts (tools) to improve humans' lives as basic concepts to guide the program.

Table 5

Outline of the 6–12 STEM Professional Development Program

Time Allocated	Content to be delivered	Participant Processes
Day 1 October	What is engineering and engineering design?	Overview of the nature of engineering, introduction of the engineering design process. Teachers participated in an activity to develop their understanding of the engineering design cycle through wind turbine blade design. Teachers ended the day in a college-level "active classroom" and had two presentations of active learning by STEM professors from the University.
Day 2 December	Math, Science and Redesign	What makes engineering different than mathematics and science? Teachers continued working through simulated student problems on engineering design—through wind turbines' gear ratios and generators; worked through a redesign activity with constraints based on their blade designs from Day 1.
Day 3 January	Problem Solving and Modeling	Teachers worked through the model-elicitation (Lesh & Doerr, 2003) process within the STEM disciplines.
Day 4 March	Integration through Technology Tools	Teachers learned a variety of ways to use technology in their classrooms as a means to integrate STEM.
Day 5 May	Representation, Translation, and Celebration	Teachers learned models of student understanding (representational fluency) through participation in a heat transfer based Engineering Teaching Kit (Schnittka, Bell, & Richards, 2010); National Speaker presented, and a poster session given as a summary to their year of STEM Integration to MDE Deputy Commissioner.

Participants and School Settings

A total of 74 teachers participated in STEM integration professional development (PD). Forty-one of the teachers were science teachers and 33 of the teachers taught subjects other than science, such as mathematics, special education, or language arts. After completion of the PD program, the researcher studied the 41 science teachers' performance by examining their Professional Learning Community (PLC) documents, STEM integration lesson plans from the PLC document, self-efficacy of teaching science/mathematics within an engineering context based on a locally developed survey (Wang et al., 2011), and final poster presentations to find potential candidates to participate in this study.

Two criteria were used to select potential participants. First, the teacher's STEM integration lesson plans demonstrated integration of at least 2 out of 4 STEM disciplines, such as science and engineering, or science and mathematics. Second, the teachers demonstrated high self-efficacy of teaching science within the engineering context from both the PLC documents and surveys. High self-efficacy might suggest that teachers have confidence and high interests in implementing STEM integration in their classrooms after the PD program. In addition, during the PD program, the researcher had several informal conversations with the teachers who participated in the PD program. Through these conversations, the researcher acquired some anecdotal data that indicated different subdisciplines of science teachers might have different difficulties in implementing STEM integration. Therefore, the researcher also intentionally selected potential participants that could represent at least two subdisciplines of science subjects, such as physical science, life science, chemistry, or earth science.

After selecting 15 secondary science teachers as potential participants from the STEM integration professional development program, the researcher asked each potential participant if they would teach STEM integration lessons in their classrooms after the PD. Five teachers (3 middle school teachers and 2 high school teachers) demonstrated high interest. The researcher recruited these five teachers for this study (Table 6). In summary, these five teachers were chosen based on three criteria. First, these participants were science teachers and they all attended and completed the 5-day STEM integration professional development program. Second, they showed high interest in using STEM integration in their classroom after the STEM integration professional development program. Third, these participants represented two subtracks of science subjects: physical science and life science. The following describes each participant and the school where they teach.

Kathy. Kathy is a white female and teaches in School A. School A is an inner-city middle school with a diverse student population. The total student population was 565. From the 2010 school report (Minnesota Department of Education, 2009), school A did not meet either the reading or mathematics adequate yearly progress (AYP) in 2010. Prior to becoming a physical science teacher, Kathy was a mathematics teacher in a middle school. She holds teaching certificates in the following areas: elementary (grade 1–6), mathematics (grades 5–8), and science (grades 5–8). At the beginning of the PD, she considered herself a novice user of STEM integration. She has 8 years of teaching experience that includes 5 years of teaching sixth-grade mathematics and science in a middle school other than School A. Currently, she focuses on teaching sixth-grade physical science at school A.

Lisa. Lisa is a white female who also teaches in School A. She teaches seventh-grade life science. She holds teaching certificates in the areas of life science (grade 5–9) and science (grade 5–9). At the beginning of the PD, she considered herself a novice user of STEM integration. She has 13 years of teaching experience, which includes 2 years as a science educator in an alternative high school and 4 years of eighth-grade earth science, seventh-grade life science, and an elective ecology class. Currently she is teaching seventh-grade life science.

Carolyn. Carolyn is a white female and teaches in School B. School B is a suburban middle school and had 737 students in 2010. School B met the reading but not the mathematics adequate yearly progress (AYP) in 2010. Carolyn holds teaching certificates in the areas of elementary (grade 1–6) and middle school science (grades 5–8). At beginning of the PD, she identified herself as a nonuser of STEM integration. She has a total of 14 years of teaching experience that includes 3 years as a nonformal science educator with a museum outreach program and 6 years of sixth grade in an elementary school. Currently she is in her second year of teaching sixth-grade physical science at School B.

Reese. Reese is a white female high school teacher who teaches in School C. School C is a suburban high school with a total population of 668 students during 2010. School C met the reading and mathematics adequate yearly progress (AYP) in 2010. Reese holds teaching certificates in the areas of chemistry (grade 9–12) and life science (grade 9–12). At beginning of the PD, she identified herself as a nonuser of STEM integration. She has 3 years of teaching experience that includes chemistry, astronomy, and biotechnology. Currently she teaches chemistry, biotechnology, and physical science. Before she became a teacher, she wanted to get a doctoral degree to become a college professor.

Sid. Sid is a white male high school teacher who teaches in School D. School D is a suburban high school with a student population of 1, 844 in 2010. School D had met the reading and mathematics adequate yearly progress (AYP) in 2010. Sid holds teaching certificates in the areas of science (grade 5–8) and chemistry (grade 9–12). At the beginning of the PD, he identified himself as a novice user of STEM integration. He had a total of 6 years of teaching experience that included physics, biology and forensic science. Currently he teaches ninth-grade physical science.

Table 6

Summary of the Participants

Name	School	Grade/Subject for STEM integration classroom observation	Teaching experience	STEM integration experience before this study	Teaching certificates
Kathy	A	6th/Physical science	8 years	Novice	Elementary, math (5–8), and science (5–8)
Lisa	A	7th/Life science	13 years	Novice	Life science (5–9), and science (5–9)
Carolyn	B	6th/Physical science	14 years	Nonuser	Elementary and science (5–8)
Reese	C	10th/ Biotechnology	3 years	Nonuser	Chemistry (9–12), and life science (9–12)
Sid	D	9th/Physical science	6 years	Novice	Science (5–8), and chemistry (9–12).

Data Collection

In order to elicit a rich and deep understanding of how teachers think about teaching, researchers need to utilize varied resources and multiple measures to draw inferences (Richardson, 1996). This data collection aims to provide appropriate answers for the research questions: 1) What are secondary science teachers' STEM integration classroom practices, 2) What are secondary science teachers' overall perceptions of STEM integration, and 3) What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices? Three different data sets, pre- and post-interviews, STEM integration lesson plans, and classroom observations were collected for this study. The data collection sequence was 1) acquiring STEM integration lessons from participants before interviews and classroom observations, 2) conducting pre-interviews with participants before they implemented their STEM integration lessons, 3) conducting classroom observations as participants implemented their STEM integration lessons, and 4) conducting post-interviews with participants after they implemented their STEM integration lessons. The following describes each data set that was collected for this study (Figure 2).

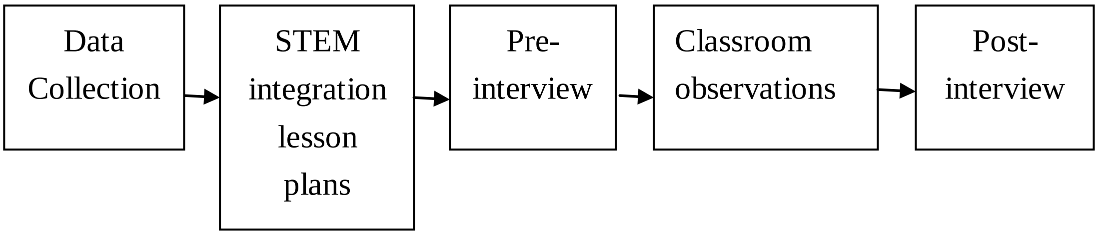

Figure 2. Data collection process.

Lesson plans. Lesson plans were collected before each participant implemented their STEM integration lesson. No specific structure or format was provided to the teachers for their lesson plans. Therefore, the format of the lesson plans varied significantly. The STEM integration lesson plans provided an overview of what the researcher might see in each participant's STEM integration classes. The lesson plans also helped the researcher to catch what the expected learning outcomes were in each STEM integration lesson. In all of the STEM integration lesson plans, teachers had identified learning objectives. The learning objectives represented what students should be able to achieve after the lesson. Therefore, before the classroom observations, the researcher had an understanding of what would be taught, what the lesson might look like, and what students might be expected to learn from lesson experiences and activities.

Interviews. Merriam (1998) suggested interviewing as "the best technique to use when conducting intensive case studies of few selected individuals (p. 72)."

Interviews have the power to reflect teachers' insight about their beliefs (Davis, 2003; Irez, 2007). There were two interviews, pre and post, conducted with each participant. Each interview lasted approximately one hour. The pre-interview (Appendix A) was a semistructured interview that was conducted before participants implemented their STEM integration lessons. The pre-interview questions were grouped into five categories, 1) perceptions of each STEM discipline, 2) perceptions related to STEM integration, 3) past experiences of implementing STEM integration, 4) goals for implementing STEM integration, and 5) difficulties and benefits of STEM integration. Each category had one to four question(s). Table 7 shows the details of the questions that were asked in each category. For example, the questions tell me about the nature of science, mathematics, engineering, and technology, was aimed at exploring teachers' perceptions that relate to each STEM discipline.

The post-interview was conducted after participants implemented their STEM integration lessons. The post-interview aimed to give teachers an opportunity to describe and elaborate on their classroom practices of STEM integration and to clarify the connection of participants' perceptions to their classroom practices. Since each participant did not implement the same STEM integration lesson, no structured questions were used during the post-interview. Although some of the questions were not the same in the post-interview, some questions were very similar. Overall, the questions still could be categorized into the following three groups, 1) classroom practices of STEM integration, 2) clarification of teachers' statements from pre-interview, and 3) reflections on their implementation of STEM integration. Table 8 used one of the teachers, Lisa, as an example to show the structure of the post-interview questions.

Table 7

Pre-interview Question Design

Categories	Questions
Perceptions relating to each STEM discipline	1. Tell me about the nature of science, mathematics, engineering, and technology.
Perceptions relating to STEM integration	1. Please define STEM integration. Does that relate to your teaching and your students' learning? How? (Can you give me an example?)
	2. What are the strengths and weakness of using STEM integration in your teaching?
	3. If giving a choice, will you use STEM integration in your teaching? Why or why not?
	4. Do you believe that STEM integration helps or could help your students learn science? In what way?
Past experience of implementing STEM integration	1. How have you integrated engineering, technology, science, and mathematic into your teaching? How do you design your STEM activity by using each discipline?
	2. Could you give me an example of the best STEM integration activities you have done?
Goals of implementing STEM integration	1. Which part of your STEM activity do you particularly want your students to understand or to comprehend?
Difficulties and benefits of implementing STEM integration	1. What are some difficulties and benefits of using STEM integration?

Table 8

An Example for Post-interview Question Design (Lisa)

Categories	Questions
Classroom practices of STEM integration	1. Why did you choose this Genetic Engineering activity? Which parts of this activity do you like the most, why? 2. Which part of this activity do you think was connected to science, engineering, math, technology? 3. Why did you choose to do your Genetic Engineering activity this way, like giving students handouts, articles to read, and the final product being a poster? 4. Would you say this activity is a STEM integration activity? Why or why not?
Clarification of teachers' statements from pre-interview	5. In the pre-interview, you said that STEM integration is a way of thinking. It is having kids create processes and their own plans for problem solving. How do you apply this view to this activity?
Reflections on their implementation of STEM integration	6. Which part of the Genetic Engineering activity do you like students to work on more, why? 7. Which part of this activity was the most challenging for students? Why? 8. Is there anything in the activity that you would like to change or improve? What parts? Why?

Classroom observations. The main focus for classroom observations was to observe teachers' classroom practices in using STEM integration. Therefore, the classroom observations were purposefully conducted during the participants' STEM integration lessons. Due to each participant having different STEM integration lessons, the number of classroom observations was varied. For example, the longest STEM integration lesson was about one and a half months, and the shortest lesson was about two days. In every class but Kathy's, the researcher stayed throughout all days of the STEM integration lesson. Kathy's STEM integration unit, however, lasted about one and a half months. Kathy suggested the idea of observing a specific sub set of these lessons and provided the researcher with a list of days that she believed would best represent her Robotics unit. Based upon this recommendation, the researcher conducted seven observations during Kathy's Robotics unit. Detailed field notes were used to record classroom observation data. The purpose for the field notes was to provide detailed descriptions for classroom practices, including details such as the content of the lectures, the language that the teacher used to deliver her/his lesson plan, and the interaction between the teacher and the students.

Data Analysis

Because of the multiplicity of data sources, data analysis in qualitative research involves an ongoing process of preparing and organizing and interaction with data on multiple levels (Creswell, 2007). The method of data analysis in this study is briefly summarized as follows: (1) open coding (Strauss & Corbin, 1990), (2) identification of patterns and categories (LeCompte & Preissle, 1993), and (3) building themes and models for cross-case analysis (Miles & Huberman, 1994).

The open coding process attempted to organize data sources by looking at the words that frequently emerged. The purpose of using open coding is to explore patterns of each participant's perceptions of STEM integration. For example, one of the research participants, Lisa, said, “STEM [integration] is a way of thinking. It is a way to teach kids, not just following the directions.” When Lisa used these two sentences, she was describing the learning goal for her STEM integration lesson. From the open coding process, thinking and not following the directions were two codes that emerged. Lisa also said, “I also think [STEM integration] gives students a set of skills that they still need to work on. The skills like creating their own methods for solving a problem instead of using a method that has given to them.” Again, creating methods and solving a problem were another two codes for Lisa that related to her goal of STEM integration. Using another example, Kathy said, “For now, STEM integration to me is not about subjects, but the problem solving process,” and “So [students] can problem solve in science and also be able to use their skills and math.” Problem solving was a code that frequently emerged in Kathy’s perceptions of STEM integration. Tables 9 and 10 give open coding examples for the five participants.

Table 9

Open Coding for Participants' Goal of Using STEM Integration (Kathy and Lisa)

Participants	Example quotes	Open coding	Patterns	Category
Kathy	1. I just like that [students] can go back to apply [content knowledge]. 2. I really do like the strengths [of STEM integration] being problem solving. 3. Engineering is high stuff for 6th graders. Doing problem solving is a huge step for them. 4. STEM integration helps kids to see the connections among [STEM] subjects.	Apply, problem solving, connection, engineering, STEM subjects	Problem solving, and connection and application	Pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration
Lisa	5. [Students] need to work on the skills like creating their own methods for solving a problem 6. [STEM integration] gave [students] a kind of self-competency to think outside the box, and the ability to really just create their own products. 7. When you do STEM integration, not everyone's solution is the same. 8. [Students] got mad at first because I didn't necessarily tell them exactly what to do [in a STEM project].	Skills, creating their own methods, solving a problem, self-competency, creating their own product, solution, what to do.	Independent thinkers, and problem solving	Pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration

Table 10

Open Coding for Participants' Goal of Using STEM Integration (Carolyn, Reese, and Sid)

Participants	Example quotes	Open coding	Patterns	Category
Carolyn	1. I think that the cyclical nature of [engineering design processes] is really important for [students]. 2. So [students] can apply the scientific concepts. My plan is that for every big scientific concept that we cover this year, we will have a culminating engineering project.	Engineering design, apply, engineering situation, scientific concept, engineering project.	Engineering design, and connection and application	Pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration
Reese	3. The whole goal is to help students understand the science concepts and be able to use the science concepts in different ways than they were exactly taught. 4. I think everything I am doing is trying to make science concepts more clear and be able to be used by the students.	Science concepts, use science concepts in different ways	Application and connection, and science content.	Pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration
Sid	5. I think [students] need to touch things…,to explore the answer by trying their ideas or experiments with different materials. 6. [STEM integration] is about thinking. It is about having your own ideas…finding ways to give more opportunities to students to solve actual problems in my class, and you have to fully integrate all contents into one. 7. If students want to get engaged [in a STEM integration lesson], they can figure out a lot of ideas and do a lot of interesting thinking.	Explore, trying and experiments, thinking, having your own idea, opportunities, solving problems, integrate all contents, ideas	Independent thinkers and problem solving.	Pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration

After gathering all the open codes, main ideas emerged as patterns. The researcher used these main ideas to identify the patterns that could represent each teacher's perception and classroom practices of STEM integration. For example, Kathy's open codes could be generalized as three patterns: problem solving, connection, and application (Table 9).

The open codes from Tables 9 and 10 were strongly related to pedagogies needed to achieve STEM integration and learning outcomes for students when using STEM integration for all five participants. Teachers frequently used the codes from Tables 9 and 10 to describe pedagogies needed to achieve STEM integration or learning outcomes for students when using STEM integration, or both. After open coding the interview data for all five participants, there were seven categories that emerged. The seven categories were: 1) the view of STEM integration, 2) pedagogies needed to achieve STEM integration, 3) learning outcomes for students when using STEM integration, 4) life skills, 5) models of implementation of STEM integration, 6) issues or difficulties in implementing STEM integration, and 7) others. Overall, participants had very similar categories, although the patterns might be varied. Because the patterns for each participant varied, the role of the seven themes is to help report the patterns from each participant in a more systematic manner. Each participant's results will be reported in Chapter 4.

The cross-case analysis followed the patterns that emerged from open coding. For a theme to emerge across cases, it needs to have been mentioned by at least two participants. The researcher examined all the patterns in the categories to find themes that should be discussed in the cross-cases analysis. After determining all of the themes, the researcher started to build a model to answer the research questions. In the cross-case analysis, nine themes emerged. The nine themes are 1) the focus of STEM integration is problem solving, 2) the focus of STEM integration is application, 3) the focus of STEM integration is engineering design, 4) the focus of STEM integration is life skills, 5) ethical issues are important in STEM integration, 6) the role of inquiry is very limited to process skills in STEM integration, 7) integration of mathematics into STEM lessons is difficult, 8) multiple strategies for integrating technology, and 9) perceived constraints to STEM integration. The cross-case analysis results will be reported in Chapter 5.

Plans for Reliability

Triangulation of data was employed. By doing triangulation, it allowed the researcher to ascertain and fully understand the phenomena under investigation. In addition, to further enhance the credibility of the study, the researcher conducted member checks by contacting participant teachers to ask them if the themes and interpretations were accurate. Peer review processes also were implemented in this study to reduce bias and subjectivity from the researcher.

Limitations of the Study

This section describes some of the limitation of this study and, when possible, how the limitations were addressed.

First, this study did not recruit teachers from subdisciplines of science subjects other than physical science and life science. Therefore, strictly speaking, the study does not represent all secondary science teachers' perception and classroom practices of STEM integration.

Another limitation is the extent to which the findings can be generalized beyond the cases studied. The number of cases is too limited for the results to be suitable for broad generalizations. In addition, this study is unique to Minnesota, in particular because the Nature of Science and Engineering standards were used as one of the major criteria to guide the discussion. However, the rich description that will be provided for the cases allows the results to be useful for all that have vested interests in science and STEM education.

The issues of bias and subjectivity are another concern. It is understandable that the researcher's personal knowledge and experience are constructed in a way that provides room for personal and subjective ways of looking at the world. Therefore, personal bias and subjectivity may have influenced how the researcher analyzed data, generated findings, and wrote the discussion in this study. However, the rigor of the research methods and peer review makes this concern minimal.

Finally, the researcher did not use a standardized observation protocol because there is currently no protocol purposefully designed to observe STEM integration classes. The researcher found it difficult to make any existing observation protocol fit the needs of this study. However, the researcher videotaped all classroom observations. Member checking and peer review of the videotapes helped the observation results in this study to reach a certain level of reliability, even without a standardized observation protocol.

Summary of Chapter 3

This chapter focuses on how the researcher designed and conducted the study. It provides a snapshot of the Nature of Science and Engineering standards, which is one of the major factors that motivated this study. Also, the methodology used to design the study and the methods used to conduct the study, as well as the limitations of the study, are detailed in this chapter. The results for the single case analysis are provided in Chapter 4 and the cross-cases analysis is reported in Chapter 5.

CHAPTER 4

Single Case Analysis

This dissertation begins with an interest in the following research questions: What are secondary science teachers' practices of STEM integration? What are secondary science teachers' overall perceptions of STEM integration? and What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices? The chapter presents the cases for each teacher. Each case includes a description of the teacher's philosophies of teaching, the case of STEM integration practices, and individual pre- and post-interview analysis. This chapter provides an overview of each teacher's classroom practice of STEM integration and his or her perception of STEM integration. As mentioned in Chapter 3, the steps of single case analysis follow: (1) open coding, and (2) identifying patterns and categories. The purpose of this chapter is to identify patterns and categories about each teacher's classroom practices and perceptions of STEM integration.

Kathy

Kathy has always loved math and science and working with kids. She believes being a teacher is a natural fit for her. She loves to have opportunities to teach both science and math. She believes that a teacher needs to build relationships with students in order to "get them" to do what needs to be accomplished. She also believes that an engaging, rigorous curriculum is important for the students that she teaches. Her STEM integration class was the Robotics unit. It was implemented in a sixth-grade physical science class in School A. Kathy did not design the Robotics unit; her school provided the curricula for her to teach.

Structure of the STEM Integration Class (The Robotics Unit)

The first case is the Robotics unit, which is a STEM integration unit taught by Kathy. The entire Robotics unit was about one and a half months long. Each class was 90 minutes and there were 24 students in the class. The unit was observed from early February to early April, 2011. Using Lego robotics kits, the unit focused on designing an assistive device, a robot, which can help people in need. The unit began by introducing the engineering design process and building a Lego wheelchair, which served as a practice prior to building the real final assistive devices. After building a Lego wheelchair, students spent the rest of the quarter designing their final assistive devices. Kathy's goals were that students should be able to (1) understand the engineering design process, (2) understand what an assistive device is, (3) understand what a constraint is, (4) program the robot computer to make it function, and (5) work and discuss with team members to complete the project.

Introducing the engineering design process. At the beginning of the class, Kathy told students that they were going to do the Robotics unit for an entire quarter. Before students could use the Lego robotics kits, though, she wanted to make sure they understood certain rules, such as the grading policy and classroom management, in order to complete this unit. For example, Kathy told students that they would need to take notes every day. She said, "The Robotics unit is not going to be super easy for you. You have to record everything day to day. You are going to take notes to remind yourself what you did. You would be graded on what you have written in your notebook." She structured students' notebooks by asking them to put the date, notes, and a conclusion. She asked the students if they knew why or how they should write a conclusion. When none of the students offered an answer, Kathy gave an example of how to write a conclusion by saying, "You are going to write one sentence about something that you learned. For example, you can say 'Today I learned how to make my robot walk.'" She also gave instructions on how to take notes. She told students, "The notes can be whatever you want to write. You can draw a picture and label it because eventually you are going to come back to your notes so you can remake your robot."

After she gave the instructions, Kathy told students, "Today we will begin to understand the engineering design process. We have talked a little bit about the engineering design process before, but now the engineering design process is going to take us through this course for the whole quarter." Kathy handed out the engineering design process worksheet (Appendix B), which has the different steps of the engineering design process on it. She instructed the students to keep the worksheet in their notebooks or folders, because it would be really useful as a reference to where they were each day in the process.

Next, Kathy gave a brief introduction about the engineering process. The engineering design process was outlined on the worksheet as follows: (1) identify the need or problem, (2) research the need or problem, (3) develop possible solution(s), (4) select the best possible solution(s), (5) construct a prototype, (6) test and evaluate the solution(s), (7) communicate the solution(s), and (8) redesign. She then told the students that they would be talking about the first five steps of the engineering design process for the next couple of weeks. She picked students to read aloud the steps and the questions on the worksheet. After a student finished reading the first step, Kathy said, "What engineers do is, they find the problems or needs. We are going to talk about this more next time. For example, what your robot is supposed to do and how you can design an assistive device," and "Engineers think, 'What can I do to make it better' to improve someone's life." After they finished reading the second step, Kathy said, "Remember the constraints? It is like certain materials that you can use, or the certain size it has to be. We are going to spend some time in the computer lab so you can do research for your devices." As for step three, Kathy told the group, "You are going to use science and math skills to help you brainstorm your possible solutions. You also need to use your imagination. You have to be creative to design your own things." She told the students that they would come up with many different solutions and that they would have to pick one of the best to test. That was step 4. Then for step 5, Kathy told the students that they would build a prototype of their robots. After she talked about the engineering design process, Kathy wanted her students to pay attention to her expectations for them in completing the robotics unit. She said,

> Every day you will need to do the warm-up questions, listen to instructions, respect all the parts of the robotics kits, clean up at the end of the class, take notes every day, work with your team, write a conclusion for what you learned every day, and work hard individually and also as a group.

To be able to use the robotics kits, students needed to sign the class contract, which stated that they agreed with all the requirements. If they did not agree with the contract, instead of using the robotics kits, students would do book work for the entire quarter. Besides introducing the engineering design process, Kathy's nether goal for this class was letting students look at the Lego robotics kits. Kathy spent about 40 minutes allowing her students to explore their Lego robotics kits. During this activity, students needed to notice the different pieces and take notes on them.

At the end of the class, Kathy told the students to disassemble everything, put all the pieces back into the right places, and put them away nicely. She wanted to make sure the students did not lose anything. After the students put the robotics kits back on the shelf, Kathy asked them if they could remember the different steps of the engineering design process and if they could talk about the different pieces of the kits. She also asked students to share their conclusion sentences.

Introducing assistive devices: The wheelchair challenge. At the beginning of the second day, Kathy asked students, "What is one device that helps you every day?" She called on students to answer this question. Students' answers included "toothbrushes", "chairs", and "pens". After that, Kathy told the students, "Today, you are going to understand what an assistive device is. And you will be able to talk to your group about how to construct your devices today." She asked students to open their notebooks and write down the definition of an assistive device, which was, "Something that helps someone perform a task." She further explained what an assistive device is by saying, "An assistive device is a thing that helps people do things that they might not otherwise be able to do. Something you might not be able to do, unless you have it." She gave an example by saying, "Like a lot of elderly people and people with disabilities use different types of assistive devices." After she gave the definition, Kathy wanted her students to brainstorm and gave some examples about assistive devices. Students' answers included "wheelchairs", "elevators", "a hospital bed", and "a cane and walkers". After students had some ideas about types of assistive devices, Kathy wanted them to do a quick reading. She showed students several articles (Appendix B) about different people who participated in the Paralympics. Students needed to choose one of them to read and to answer the questions on the back of the articles. After she gave students about 15 minutes to read the articles, she had them share the articles by asking what students had learned.

After reading the articles, Kathy introduced the wheelchair design challenge to the students. She said,

> You are going to use your robotics kits to build a wheelchair. Here are your constraints. The wheelchair must be at least 8 inches tall. Your wheelchair must be able to roll while holding a block. Your wheelchair must pass a drop test from 3 feet. Your wheelchair must be made from the Lego kits, but not the computer things, such as a sensor or a motor.

Kathy also gave students a piece of paper and said, "You might not be able to finish this today. What you can do is write some notes on this paper, and also I will take pictures of your wheelchair for you to remember what you did." She told students to get their robotics kits to work on the challenge. Students started to build their wheelchair. Kathy walked around helping students if they had questions. For example, as Kathy walked around, she found that a group's wheelchair did not have enough space to hold a block. She asked the group if they thought it was big enough to hold the block and they replied, "Yes." Kathy then told them to get a block and test it and then reminded the group that they had to meet the constraints. Another group's wheelchair was not tall enough. Kathy asked them to check the height of their wheelchair and again reminded the students of the constraints.

At the end of the class, Kathy gave some time to the students to write their conclusions. Then she asked students to share their conclusion with others.

Doing the research. At the beginning of the third class day, Kathy asked, "What is a constraint? Remember the wheelchair challenge? It has to be 8 inches tall and has to survive from a 3-foot drop. We will talk constraints a lot more as we go through the whole quarter." Kathy told the students that they would be able to research assistive devices. She stated, "Engineers need to do research a lot of time. They need to do research to figure out what kinds of things have already been done." She then told the students that they would go to the computer lab and use the Internet for their research. She gave them specific instructions about what she wanted them to do in the lab. For example, Kathy told them that when they do their research, one website may not give all the information that they want. She said, "When you Google 'assistive devices,' you probably need to look at a couple websites to get what you need." She said to her students that they could type "example of assistive devices" as key words to do their research. She passed out a worksheet (Appendix B) that students needed to complete for this class. In the worksheet, students needed to find three different assistive devices and fill in information about the names of the assistive devices, sketch pictures of the devices, list who the devices help, and the function of the device. Next, Kathy moved the students to the computer lab to do their research. She walked around helping the students who had questions. In the computer room, a student said, “I don’t know what I am looking for.” Kathy said, “You have to look through all the options that show up on your computers. Like I told you, doing research, you have to look at a lot of websites.”

At the end of the class, Kathy picked some students to share their conclusions with the whole class.

Programming a robot. On the fourth day of class, Kathy told her students, “When we talk about programming something, we are kind of telling it what to do. Today, you are going to learn how to program and you are going to learn how to download that onto your robotics computer.” She wanted students to write down the definition of program; “a set of instructions enabling a computer to solve a problem or do a task.” Then she showed students how they could program their robots. For example, she had the program on the interactive whiteboard and said, “When you log in a computer, you look for Common Palette. What we are going to look at today is playing sounds, display, and drive forward.” Furthermore, she said, “Sometimes [the program] plays a little video on the side for you, so you can drag the sounds over here [on the computer screen] and you can pick different things for [the robots] to say.” She showed the students how to download a program from a laptop to a robot computer and the cord they would need in order to do this.

After that, she gave each group a laptop to work on their programming. She said, “Make sure everybody gets a chance to try to program your robot.” She told students to explore all the programs in the computer and explained, “You get to decide what your robot will do. So, just explore the options in the program and think about what you want your robot do."

Kathy walked around helping students to program their robots. For example, she said to a group, "Open a new file. Now you can watch these things [tool icons] and you can see what these things can do. Now you can drag that into your program." Another group showed something to Kathy, and she exclaimed, "Oh, wow! How did you do that? That is cool. Show me how you did it!" When students asked questions that Kathy did not know the answer to, she said, "I don't know. Let's see. Have you tried this [tool icon] yet?"

At the end of the class, Kathy picked some students to share their conclusions with the whole class.

Introducing final project. Kathy started the sixth day of class by asking students, "Why do engineers work as a team?" Students' answers included, "to make their work easier," and "to have more ideas that they can solve their problems." Then Kathy told students that they were going to start their final project. The goal for this class was to have students complete the engineering design process from steps 1 to 3. She said, "You are going to do a lot of planning today and maybe a little bit of research. Then you are going to go step by step to figure out how you are going to build your robot." She once again emphasized the engineering design process by saying, "The engineering design process is what engineers follow when asked to solve a problem." She told students that step 3 is what they were going to focus on today. She then gave one project package (Appendix B) per group to the students. She reviewed the challenge by explaining, "We presented this problem a long time ago. For your final project, you have to create an assistive device. Remember? We did the research a long time ago." She wrote down the challenge on the interactive whiteboard and said, "We will design and program a robot that is an assistive device." Then she said, "Again, who can tell me what an assistive device is?" Students answered, "It is a device that helps people." Kathy agreed and told the students that they would design and program a robot to help someone do something. She then reviewed step 2 by saying, "Step number 2, constraints…like how much time do we have to complete the project? So your project needs to be done by April 7th and that includes design and programming your robot, and a PowerPoint presentation." After that, she explained, "Step number 3 is about research. We have already done that. Remember? We were in the computer lab? However, we might need to do more research." Then, Kathy showed some video clips and told students that they might get some ideas on how to design their robots from other peoples' designs. After the video clips, she gave each group a laptop and said, "So, you are just going to do research today and decide what you want your robots to do and who you want to help. You are going to make a plan with your partners today." Then, she walked around helping students with questions. For example, Kathy asked one group if they had decided what their robot would do. Students replied, "Hit balls." Kathy then asked them how that would help people and a student in the group said, "I don't know…maybe help people who want to hit balls?" Kathy told the group to think more about a good reason to help people if they wanted their robot to hit balls.

At the end of the class, Kathy picked some students to share their conclusions with the whole class.

Thumbnail sketches and design. At the beginning of the seventh day of class, Kathy told the students that they were going to practice a thumbnail sketch and asked them to write down the definition. She told them, “A thumbnail sketch is a small drawing often used to brainstorm many ideas at one time. Engineers often make thumbnail sketches with their ideas. Engineers brainstorm and draw sketches. Then, they decide which one they want to try out.” Kathy said, “Our objective today is you are going to move a step forward to complete your thumbnail sketches and design. Also, you are going to practice building your robot.” She told the students that they needed to communicate with their partners about their plan, because they have to be on the same page in order to build their robot together. She told them, “Our major language objective is that you will be able to communicate with your partner about your plans.” Then, she asked students, “What is design?” She asked students to write down “Design: to make drawings or plans,” in their notebooks. Then, she said, “Today, your job is to do a thumbnail sketch and design your final robot. By the end of the class, you will have to complete your sketch and tell me about your design.” She told students to get their Lego kits and explained that after they had their sketch, they could try to use Legos to assemble their robot. She elaborated, “For example, if your sketch has a claw on it, then you need to make sure you can build a claw by using these Legos.”

At the end of the class, Kathy asked her students, “Have you had a chance to take a look at other people’s design? Some people plan to use different sensors and make their robots do different things. You can get some ideas by looking at others.” She also asked the students to share their conclusions with their group members.

The last day of the Robotics unit. Kathy started the 10th day of class by asking students, “What are you most proud of about your robot design?” A student said, “I don’t like my robot.” Kathy asked why and the student replied, “I want a swing arm, but I don’t know how to build it.” Kathy said, “Today you will have time to redesign your robot. You can ask other people about how to build a swing arm.” Then, she said to the entire class, “Today, you will have a chance to change your design to make it final. Why do you think engineers need to do redesigning?” A student answered, “If it does not work out as they have planned.” Another student said, “Maybe they didn’t like it.” Kathy said, “Engineers always want to make things better, so they spend time changing their design. For example, maybe they can change to cheaper materials, or make it smaller, like your cell phone.” Before she let students work on their robot, she reminded them that today was the last day of the Robotics unit. Students would need to work on their robot and also their PowerPoint presentation because they would need to present it during the next class. She reminded the students, “Remember, in your presentation, at least you have to tell us what your assistive device is, who your assistive device helps, and what your assistive device can do.”

Again, at the end of the class, Kathy asked students to share their conclusions for the day with others.

Interview Results

Kathy's view of STEM integration. Kathy believes that STEM subjects are highly related with each other. She said, "I think to integrate [STEM subjects] is fairly natural." She defined STEM integration as "using your math, science, technology, and engineering knowledge to do problem solving. Using those things you have learned to figure out how to do something." Her view of STEM integration could not be separated from problem solving. She said, "I guess when I think about STEM integration, it is kind of back to that problem solving." She believed that the major commonality of STEM subjects was doing problem solving. For example, she referred to engineering as a way of problem solving, which was related to what scientists do. She said, "Scientists and engineers do things for a reason. It is like they have problems that need to be solved. In my class, with engineering, we [Kathy and students] try to do a lot of inquiry stuff with problem solving." In fact, problem solving was a major focus in every one of Kathy's classes. She said,

> I used to teach math. In my math classes, I tried to focus on problem solving. As for engineering, I think a lot of things have to do with problem solving because of the engineering design process. In science, we do a lot of inquiry and that is a way of problem solving, too. So I think that most of those [integrating STEM subjects] have a lot to do with problem solving.

One of the biggest reasons that Kathy centered her teaching on problem solving was due to her school's mission. Kathy's school aimed to build students' problem solving skills and to develop students' experiences for their career interests in engineering. She explained, "Our school does a lot with problem solving, not just in science and math. We have talked about problem solving methods in our classes for years. We have taught engineering design in our science classes, too." Therefore, teaching engineering is a major part of Kathy's job even though she is a science teacher. She also said, "Our school is focusing on engineering. We focus more on engineering than STEM integration." She said, "I feel like right now we [the school] are on the 'E'[engineering] and 'T' [technology]. There is not much 'S' [science]." She described her Robotics unit as a stand-alone lesson that is highly related to engineering and technology, moderately integrated with science and even less integrated with mathematics. She said,

> It [the Robotics unit] was kind of a stand-alone engineering type of lesson. The technology part was the programming on the computers and students' presentation by using PowerPoint. The engineering part was definitely following the engineering design process, which is tied to sixth-grade science standards. The math was kind lacking in that. The science was basic, like inquiry, like the problem solving and building and trying to figure out how to put the robots together.

Kathy also considered her Robotics unit as "building engineering science type of things." To Kathy, integrating engineering was using the engineering design process. As for integrating technology, she considered that computer devices were the primary technologies that she would use in her STEM lessons. She explained, "Now our school is getting more technology. It is easy for us to start incorporating the laptops and use online resources. Also, we can ask kids to do PowerPoint presenting rather than pencil and paper."

Because the robotics unit was given to Kathy by her school to teach, she felt that it could not represent her view of STEM integration. She said,

> Actually I didn't choose the [Robotics] unit. It was given to me. I had to teach it this year. So that was that. We did a lot of technology and engineering. I didn't think just because we did engineering that we were doing STEM. I didn't like that, but I had to do it.

When asked about Kathy's real view of STEM integration, she described it by saying,

> I love to be able to teach science and maybe some of the math. Then, we [students and I] do some sort of engineering projects that use those [science and math concepts]. Then, somehow integrate whatever technology I can fit into that. That is actually my view of [STEM integration].

Kathy's view of STEM integration was placing science as the foundation of her STEM integration lesson, and using engineering as the glue to tie science and math concepts together. Technology was the last piece that she would integrate into her STEM integration lesson.

Pedagogies needed to achieve STEM integration. Kathy believed STEM integration could mean a lot of different things depending on how teachers used it. For example, she said, "I think a lot of people have this mentality that when you think about STEM, you think like a hands-on project, but I know that a hands-on project is not necessary for STEM." Kathy's STEM integration lesson focused on helping students become problem-solvers. In her Robotics unit, she focused on both inquiry and problem solving. She said, "[The Robotics unit] in the science part is pretty much is inquiry and problem solving, like how to put the robots together." To Kathy, inquiry played a very important role for students to be able to solve a problem. She believed that inquiry and problem solving were slightly different and distinguished the differences by saying,

> Problem solving is like using different steps to solve problems. It is like understanding the problems, making a plan, solving and checking it. Inquiry is where I let [students] struggle, kind of giving them problems and having them try to figure out the problems.

To Kathy, STEM integration was a teaching strategy that she could use to teach her students about problem solving. She focused on problem solving skills or problem solving processes rather than content knowledge or STEM subjects. She stated, “So far in my teaching, STEM integration is not about subjects, but the problem solving processes. For me right now, [STEM integration] definitely has less content.” This also showed when she talked about how she integrated math into her other STEM integration lesson. She said,

> We do a lot of graphing in science to help strengthen math skills. So [students] can problem solve the science and also be able to use the math, not so much basic math skills, but more like analytical math that actually focuses on the problem solving in science.

She considered the engineering design process to be a very important part for her STEM integration lesson. One of the reasons that she used the engineering design process in her teaching was because of the state standards. She said, “For the Robotics unit, specifically that one is following the state standards’ engineering design process. After the lesson, I can check [the engineering design process] off my list.” In addition to that, another reason Kathy taught the engineering design process was because she believed that integrating engineering helped her students use problem solving skills in a very natural way to solve a real-world problem. She said,

> [With integrating engineering] I just really try to focus on problem solving in a real-world situation and to come up with different solutions. I like to leave things open-ended so that they [students] can do their lab to try to make their own things, and to create and to be creative by using these steps [of the engineering design process].

Therefore an open-ended, real-world problem was a necessary component in Kathy’s STEM integration lesson. She said, “When we do problem solving, I don’t give [the students] answers. I make them figure out the problem by themselves," and "[In a STEM integration lesson] we talked about real life things and issues and we solved problems, not just in school or in textbooks, but in the real world."

If it were possible, Kathy would like to focus her STEM integration lessons more on science content rather than engineering. She wanted her STEM integration to use engineering to do some small projects that can support the science content that she wants to teach.

Learning outcomes for students when using STEM integration. One thing that Kathy wanted her students to learn from a STEM integration lesson was to solve a problem themselves. In her STEM integration lessons, she wanted her students to see the connections among STEM subjects. Furthermore, she wanted her students to understand and to be able to use both scientific knowledge and the engineering design process. She said, "I just like that [students] can go back to apply [content knowledge]." Kathy used another STEM integration project, Rube Goldberg, as an example to express what she would like her students to learn from a STEM integration lesson. She said,

> I didn't really care if [students] built a successful product or not. I really wanted them to look at the process and to be able to answer those questions about what they did. For example, after the [Rube Goldberg] project, I wanted them to think back and tell me what and how the energy transformation did from their machines.

She stated that a big advantage to doing STEM integration was to let her students use their own thinking to solve a problem. She said, "I really do like the strengths [of STEM integration] being problem solving. I like to have kids do a little inquiry, thinking on their own and not always get the answers." Kathy felt her students needed more practice to do problem solving. She said, “Engineering is high stuff for sixth graders. Doing problem solving is a huge step for them.”

Kathy valued the problem solving processes that helped her students to become independent thinkers. She believed students were really learning something when they struggled. She said, “Once you problem solve something for yourself, you know how to do it and you don’t forget it. Instead of when teachers tell you things, you forget it.” She used her Rube Goldberg STEM integration lesson to further explain her points about why she wanted her students to use their own thinking to learn science. She said,

> I think when [students] are able to discover [that energy transferred] and actually see it, and then make it work themselves, they remember that a lot more and they are able to explain it and tell about it. When they are able to create things on their own and figure out how to make their Rube Goldberg work, it just makes learning science a little bit more fun. [The Rube Goldberg project] helps them to learn science.

Kathy believed that using one’s own thinking to solve a problem is a life skill, and that it is something that her students needed to master, even beyond the science classroom. She believed all students could benefit from STEM integration, even though they might not choose a STEM field as their career path. She said,

> STEM integration helps kids to see the connections among [STEM] subjects. For example, [students] might not be strong at science and engineering, but they are strong at math. STEM integration helps them and supports them to learn things from other fields…Even though they are not strong at any of [the STEM subjects] or they don’t want to have a career in STEM fields, I think that goes back to problem solving again. Problem solving skills are the life skills that they need to have regardless of if they want a STEM career or not.

Life skills. Kathy described how her students felt that they could not get an answer from her when they did the Robotics unit. She said, “The kids were really excited when they were able to do that [making their robot work]. And they were really frustrated when they couldn’t do it.” Although sometimes students felt frustrated during a STEM integration lesson, at the end Kathy felt that they realized that they could achieve something that they thought they could not do. She said, “They did get really frustrated, but they also felt a huge sense of accomplishment when they actually got something done, like ‘Wow, this works?’ and it was really cool for them.”

Models of implementation of STEM integration. Two important characteristics could be used to describe Kathy’s implementation of STEM integration: units and subjects and how to teach STEM integration.

How to implement STEM integration in different units and subjects. Kathy was a math teacher in a middle school for several years. Comparing math and science, she considered it easier to use STEM integration in a science class rather than in a math class. Although she believed using STEM integration in a science class was fairly natural and that it was easier than in a math class, she did not think that she could use STEM integration all the time in her science classes. She said, “[STEM integration] is like inquiry. You cannot use inquiry all the time in your class. Some things you just have to explicitly teach, like what force is.” Kathy believed that doing STEM integration really depended on which science units she was teaching. She believed that some science units were easier for implementing STEM integration than others. She said,

> I don’t think about STEM integration the whole time. It is easier to do STEM integration in some units, such as force, motion, and energy, than some units, like matter. I think it is because we do a ton of problem solving, and I can easily integrate some math in that, like using equations.

How to teach STEM integration? Kathy believed students needed to have at least some content knowledge before they could do STEM integration. She said, “I think it will be good to be able to build up a lot of knowledge at the beginning. [Students] can use all that information to help them, you know, integrate [knowledge] into engineering projects.” Kathy believed that when students possessed a certain amount of content knowledge, they could have more meaningful learning when they did a STEM integration project. Kathy used her Rube Goldberg STEM lesson as an example and said, “When we did the Rube Goldberg project, kids had learned about energy transformation already, so they had to say things about energy transformations as part of their work when they designed their products.” Therefore she believed the best time to do a STEM integration lesson was at the end of each big unit, such as a force unit. She explained, “I really like to use STEM projects at the end of every unit that I teach. The application features of STEM integration help my kids to really apply what they have learned.” Kathy believed when students had the content knowledge that they needed, they could really use that knowledge in their design. She explained further,

> I want to change the curriculum a little bit, so that they [students] have a lot of knowledge at the beginning. Then, throughout the year, they do engineering-type labs or projects, because they need to practice [the engineering design process] over and over again. In that way, they can use what they know about science and math to figure things out and do engineering things.

Issues or difficulties in implementing STEM integration. Kathy established five concerns or difficulties in planning and implementing STEM integration. First, she struggled with the lack of technology to do STEM integration meaningfully. Second, she was concerned about her students’ abilities to do STEM integration, especially in connecting content knowledge with STEM projects. Third, she considered herself a novice in using STEM integration. Therefore, she struggled with how to design and use her STEM integration projects. Fourth, Kathy felt exhausted because she needed to repeat her Robotics unit with six different classes. Finally, Kathy was aware that student motivation played a key role for her to successfully implement STEM integration. In addition, she had a hard time balancing the fun part and learning part of her STEM integration lesson.

About technology. Kathy believed her students' ability to use technology and the technology resources that a school could provide were two reasons for her to question if she wanted to integrate technology in her STEM integration lesson. She said, "Kids are good with technology, but that is limited to just playing games or downloading music. If we talk about doing PowerPoint presentations or online searching, they are not good at those." She was surprised to learn that her sixth graders did not know a lot about how to use the Internet to do research. She said, "I think technology pieces definitely are the part that I want to work more on in the future. I think our kids are a little behind in technology." In order to integrate technology into her teaching, she needed the proper tools. She said, "I think the technology piece is the hardest part for me to do STEM integration, mainly because we just don't have a lot of stuff in our school."

Students' abilities to do STEM integration. In Kathy's ideal STEM integration lessons, she wanted her students to use their scientific knowledge and the engineering design process to create or design their engineering products; therefore, she needed to teach content knowledge at the beginning. She said, "There are a lot of things that you have to just teach. Especially with sixth graders, you just have to teach them what speed is, because they don't know what speed is." Kathy believed that her sixth graders were also still learning how to do problem solving. Problem solving skills do not come naturally to a sixth-grade student. Kathy was convinced that in order to do STEM integration, her students needed more direct teaching at the beginning to learn content knowledge. Therefore the hardest part for Kathy in doing STEM integration was how she could wisely combine content knowledge and problem solving. She said, "To me, figuring out how to teach [content knowledge], and then take [students] into problem solving is difficult." From her experience, she discovered that her students had a hard time connecting what they had learned with what they built and what they wanted. She believed this was a big issue that she needed to figure out in her STEM integration lessons. She said,

> [Students'] brains still try to connect all the information that they had learned to what they want and what they do. You have to explicitly teach all the content knowledge that they need. How can I make [students] learn what they need to learn in science and also use that knowledge in their engineering project to do problem solving? I think that is really hard.

In addition to that, Kathy also was aware that her students had a hard time working as a team. She believed sixth-grade students also needed to learn how to do team work. She said, "We talked about why engineers are working as a team. [The students] got it, but sometimes they just didn't work very well as a team, even though they got to pick their partners."

Doubts. Kathy constantly had doubts about how to design her STEM integration lesson and was convinced that she did not do a very good job. She believed that she needed to learn more about STEM integration to help her students to see the connections among STEM subjects. She said, “It is not like I don’t know how to do STEM integration. It is more like how can I make those connections [between STEM subjects] for [students] and help them see the connections,” and “I am still learning how to teach STEM integration. I just don’t know what would be a better way to do it, or what would be an efficient way to teach STEM integration.”

The battle between Kathy and her school’s mission was another reason that she had doubts about how to teach STEM integration. She said, “Because we are going to be an engineering school that was why pretty much I focused on engineering, even though [the Robotics unit] was taught in a science classroom.” According to Kathy, the way that she taught her Robotics unit was the way that her school wanted her to do it. It was not what she wanted to do in her STEM integration lessons. She said,

> The [Robotics] unit was too long. That is what [the school] wants. I have to focus on engineering. I really think if I do it again, instead of a whole quarter, I want to shorten this unit to maybe like a month long lesson and make it not as a stand-alone engineering unit. I’d like to add science and maybe some math content in it. In that way, I think I should be able to make it more STEM integrated.

Too many class sessions. Kathy had to teach her Robotics unit to six different classes. After each class, she had to ask students to take apart the robots that they had built because she needed to get ready for the next class. Therefore, students had a hard time tracking what they had done previously. She said, “[Students] told me that they didn’t like having [their robots] taken apart. So, that was a big challenge.” Teaching six different classes made the Robotics unit a big challenge for Kathy. She constantly needed to remind her students not to abuse the Lego robotics kits that they used to build their robots. With sixth graders, it was hard for Kathy to make sure the students did not lose any of the pieces. She said,

> I have to teach six classes. If I have to teach this [Robotics unit] again next year, I will do some sort of rotating schedule for a month or two months. Too many classes share very limited Lego kits. I can see all the tiny pieces flying around the whole classroom. That is not fun at all.

Fun vs. learning. Kathy felt if she could get students to do problem solving, she had done a very successful job of teaching. She believed motivation to do STEM integration was a big issue for some of her students. She said,

> You can make [a STEM integration lesson] fun, but you cannot force any kid to do anything. I definitely think a huge issue is the motivation. The kids can do a good job, but they just choose not to do it. They are just not motivated and I have no idea why.

To Kathy, a STEM integration lesson helped engage her students to learn because it was fun. She said, "[Students] love it! They think it is so cool." She used the Robotics unit as an example and said, "I guess I really like to see students that were into it [the Robotics unit]. I think it is really fun to watch them do that and they [students] think it is fun, too." Kathy reflected on her Robotics unit and said, "They [students] kept pushing themselves 'Oh, we can do that. We can add this to it.' Sometimes they got too excited about building their robots and forgot to do other things, like note taking."

Kathy believed it was very important for her students to track whatever they did, such as writing notes every day, for a STEM integration lesson. Therefore, she designed a package for her students to record each step of what they did. She said, "It is important that you record all your stuff on the [engineering design] process. You follow that [package], you record each step, and look back on that." However she found it was hard for her students to sit down and write down what they had done for a day. She said, “For some reasons, like some of the kids even though they were totally motivated and engaged, they didn’t do that part of their package for the day.” In each day of her Robotics units, Kathy gave her students some time to reflect on and to write down what they did. However some of her students just did not complete their package for days. She said, “If they did not do that [reflections and notes], I would not know what they had learned from that day. I felt they just put their robots together without thinking why they did that.”

Other. Kathy valued student-centered learning. She liked students to figure out a problem by themselves. She said, “Basically, I don’t want to do a lot of direct teaching. I don’t like to tell them [students] ‘Do this and do that’. I like them to figure out things by themselves.” Kathy believed one of the advantages of using STEM integration was that her lesson became more student centered. She said, “I loved it [a STEM integration lesson]. I felt I don’t have to do as much as in a regular class. I think when kids learn on their own, they understand it better.”

Kathy believed another big advantage of using STEM integration was to show the connections among STEM subjects to her students. She said “A huge benefit [of using STEM integration] is to be able to make connections with the things that they [students] have done and the things that they have learned in different STEM areas.” She believed most of her students had no idea why STEM subjects needed to be used together in order to solve a real-world problem. She stated that STEM integration helped her students to see the connections. Seeing those connections also helped her students explore their career paths. She said, “I think that [STEM integration] helps them [students] get excited about those [STEM] types of subjects. They can explore those options and find out if they really like one of those areas.”

Lisa

Lisa has always enjoyed the middle school age and the rewards of watching the students grow as people, share their experiences, and learn. As a middle school science teacher, she believes students need to be engaged in science learning through actively doing science, connecting their classroom learning to life experiences, and drawing their conclusions based on observations and data. She wants her students to come away with skills that help them handle future science classes, problem-solve, and think through problems in a step-by-step format that allows them to work toward solutions confidently.

Structure of the STEM Integration Class (Genetic Engineering Activity)

The next case focuses on the Genetic Engineering activity taught by Lisa. The Genetic Engineering activity was implemented in a seventh-grade life science class in School A. This activity was part of her Genetics unit. The entire Genetics unit was about three weeks long, and the Genetic Engineering activity was 2 days. The activity was implemented at the end of her Genetics unit. Each class was 90 minutes and there were 26 students in the class. The activity was observed in early January 2011. The activity focused on designing a genetically modified organism (GMO). Based on the Genetic Engineering activity, Lisa wanted students to be able to (1) describe genetic engineering and selective breeding and give examples of their benefits to society, and (2) create a mythical GMO that benefits society in some way. The following describes the details of each day of the Genetic Engineering activity.

Day 1. Day 1 had two goals: (1) an introduction to genetic engineering and genetically modified organisms (GMO), and (2) designing a GMO that would benefit society in some way. Lisa started the class by reviewing Punnet Squares. After the warm-up, she asked students to take out their genetic engineering packet (Appendix C). This packet contained step-by-step questions that students needed in order to complete this project. She told the class, “Before the break, we talked about what genetic engineering is. Today you are going to invent your own genetically engineered organism. Does anyone know what exactly genetic engineering is?” Then, she showed a PowerPoint slide that had some fake genetic engineered animals on it. For example, on one slide there was an animal that was made by combining a zebra with a sea lion. Lisa explained, “The idea is for you to think creatively when you come up with your own genetically modified organism. The idea is to take a gene from one organism and put it into the chromosomes of another.” She also gave students an article that they needed to read that talked about real genetically engineered organisms. For example, the article talked about a goat that had a gene from a spider, so the goat’s milk contained tiny strands of spider silk which can be made into a strong, stretchy rope. After providing some examples of GMOs, students watched a film about how genetic engineering helped agricultural production systems in California. The film contained information on what genetic engineering is, and how GMOs benefit agriculture in California and why it is important to be aware that some people consider GMOs to be a bad idea for our society. After the film, Lisa said,

> We are going to continue the research phase of your project. This is the second reading you are going to do today [Lisa points to the article]. There are six questions in your genetic engineering packet that you need to answer. This is step 2, the research phase. These questions are from your second reading. You and your partners are working together to answer these questions. You should be able to find the answers very quickly, because the questions also tell you which pages in your article that you can find the answers.

Then, she said,

> After the research phase, you are going to go back to step 1 and start brainstorming with your partners, 'How can you create a GMO that has a benefit to society?' For example, maybe your organism can increase the quality of food.

Lisa put up another slide and explained what she meant by being beneficial to society. She said, "Lots of GMOs make crops grow better and faster or keep bugs away from crops. So, a benefit to a society can be helping people, producing medicine, keeping bugs away from crops, or other things." Furthermore, Lisa made sure the students understood that after the research phase they needed to go back to step 1 of their genetic engineering packet. They would need to answer these two questions: (1) Why do some people think GMOs are bad? (2) What good points would your organism have? Lisa emphasized the importance of completing step 1 by reading the questions aloud. She told students, "Once you come up with ideas together with your partners, you need to move on to step 3, designing your organism. You need to have a sketch for your organism." After that, she showed some examples of what other students did last year for this project. She explained,

> Genetically creating an organism is really expensive. It costs a million dollars to really create a GMO. We are not going to really genetically produce any organism. We are going to do this either on a poster or build it with some crafts. You are going to give your organism a name. Because

> it is very expensive to create a GMO, you should have a name that is really appealing.

She told students that she would like them to finish the sketch of their GMO, and complete steps 1 to 3 of their genetic engineering packet by the end of this class. After she explained everything, she let her students work as groups to complete their genetic engineering packet and to design their GMO.

Day 2. Day 2 had two goals: (1) an introduction to selective breeding, and (2) continuing to finish the GMO project. Lisa started day 2 by asking students to give real examples of genetic engineering. She said, "I want you to think back to the reading that you did last time and give an example of a real genetic engineering organism that scientists have built. Who can think of anything?" A student answered, "A glowing cat with a jellyfish gene." Another student said, "A killer moth that kills caterpillars by passing disease genes." Then, Lisa said,

> We are going to do a quick review…you have done some genetic engineering research and answered questions in your packet. I want you to flip back your notebook and turn it to your note section. You need to write down this, 'What is selective breeding?' This is a good and old-fashioned way of selecting organisms.

Then, she started to read an article in the genetic engineering packet about modifying plants and animals. After she read the article, she said, "So that kind of scientific manipulating of an animal or a plant has been going on forever. Farmers chose the strongest and the best animals to breed, and that is selective breeding." She gave some selective breeding examples to students, such as a Goldendoodle, which is an offspring from breeding a Golden Retriever with a Poodle. She explained how this worked and then said, "The next term I want you to write down is 'genetic engineering.'

So genetic engineering is splicing a gene from one organism and placing it into the chromosomes of another." She compared genetic engineering and selective breeding by saying, "When we talk about genetic engineering it is different from selective breeding, because you are not choosing a mother and a father and breeding them, rather you are changing their genes."

After explaining the differences between selective breeding and genetic engineering, she passed out a grading rubric (Appendix C). She said, "This is how you are going to be graded on your genetic engineering project. Because there are a lot of parts in this project, this can remind you of the details that you need to pay attention to." She explained each item on the rubric to students to make sure they understood her expectations for their final product. She told the class, "I will grade your project by how you complete your [genetic engineering] packet, like if you complete research questions, if you have a plan, and if you and your partners work together to create your GMO…"

She also wanted students to evaluate each other's work. She explained,

> Today you are going to evaluate each other. I want you to think if this project is worth it to be funded. This is very important, because not all the scientific projects will be funded. You can ask other groups to explain why they think their GMO is worth it to be funded and you will tell the group why you think this should or should not be funded. You should write down your comments and how they should change their product. Give them some good feedback to help them make a better product.

Then, she showed some examples from the past year of how students critiqued each other's work. For example, a group created a flying Komodo dragon as a pet. The group made the dragon as a pet because they did not want it to be scary. The last thing

Lisa said about the grading rubric was about presenting. She wanted students to share their posters. She said,

> At the end of today, if you feel your poster is not done and you need more time, we probably will do the presentation next Monday. But you need to prepare to say something about your poster. One thing you want to do for your presentation is that you want to convince us of the usefulness of your product as well as your explanation of it.

After that, she let her students work on their GMO. She walked around helping them and answering their questions. A group came to her and said that they wanted to create a tiger that has shark genes. However, they didn't know how this animal could have benefits to society. Lisa told them, "Thinking about a tiger and a shark's personality, what are the good things about them and the bad things about them?" Another group also had a question about what to write for their GMO's benefits to a society. She said, "You just write down what you just told me about and that is how you fill your packet." A group wanted to create a chicken that could produce ice cream and French fries. They came to Lisa and asked how they could do that. Lisa asked them, "Where do ice cream and French fries come from?" The students replied, "Cows and potatoes." And so Lisa told them, "So, whatever the genes in the chicken reproduction system, basically replace that potato and cow genes in to the chicken." The group said, "We are going to name our chicken McChicken." A group wanted to create a cow that could produce Coca-Cola. They did not, however, explain what they needed to do to make their cow produce Coca-Cola. On the poster, they just wrote, "I squirt out Coca-Cola instead of milk!" Another group wanted to create a woman with an Afro hairstyle that could turn into a pencil sharpener. They also did not explain how they were going to do that.

Interview Results

Lisa's view of STEM integration. To Lisa, STEM integration could not be defined by how many STEM disciplines she needed to integrate into one lesson. Instead, she defined STEM integration by how she could use mathematics, engineering, and technology in her science classroom to teach students to do problem solving by using their own thinking. Lisa valued letting students use their own thinking to solve a problem and indicated that this is one of the most important qualities in STEM integration. She said, "STEM [integration] is a way of thinking. It is a way to teach kids not just following the directions. There is no wrong answer. In the real world, scientists do not follow step-by-step directions to do their experiments." Therefore, most of the time when she talked about STEM integration, Lisa did not refer to STEM as a lesson plan, a unit, or an activity, but as a process—a thought process that helped students to think independently like real scientists. She believed an open-ended question that had open-ended solutions with no right or wrong answers was the key to STEM integration.

Lisa considered STEM integration to have unique characteristics that helped her students understand a problem that could be solved and could have various answers. She said, "STEM [integration] is a process where kids come up with their own plan for problem solving. It gives them a sense of open-mindedness. It is like an open-ended question that has a different solution." In her science classroom, Lisa was convinced that thinking independently was a new way of thinking for her students because they did not have lots of chances to use their own ideas to solve a problem. She said "[STEM integration] is a very different way of thinking for [students] because in science, students end up doing lots of lab activities and experiments where everyone comes to the same conclusion at the end." Therefore, STEM integration provided her an opportunity to teach her students about what real scientists do for their jobs. She said, "I think [STEM integration] feels more like real science. I think it gives kids many more real feelings about what scientists are doing as a career."

Lisa's priority for her STEM integration lesson was helping her students to become independent thinkers as real scientists are by practicing problem solving processes. She believed that in the real world, scientists and engineers use a lot of imagination and creativity. She asserted that an open-ended question could evoke her students' imaginations and creativity. She said, "[Students] are creating. It is not necessarily going to match what everybody else does. They can come up with absolutely anything." For example, one of the STEM integration activities that she had done was to create a moon colony. The purpose of the activity was to teach the scientific concept of photosynthesis. Students needed to create a little biological community in a small bubble. During the lesson unit students needed to think about the things they wanted to put inside the bubble to make the atmosphere breathable. Students used their imagination to create all kinds of different things to make the atmosphere breathable. Lisa said,

> So [students] were coming up with an invention that didn't necessarily exist, but that would be something that their moon colony could use. [Imagination and creativity] helped them to come up with their own answers and ideas that were different from others.

Pedagogies needed to achieve STEM integration. The new Nature of Science and Engineering standards were the biggest push for Lisa to use STEM integration in her class. She stated, "Since the science standards have changed this year, most of my time is devoted to changing what I have been doing to fit the new standards." Besides independent thinking, her STEM project also focused on the science content that she needed to teach. She said, "[Science] Content knowledge is my major focus in a STEM lesson. Surrounded by that, I add more STEM disciplines." She defined engineering as, "A series of steps that you go through in order to come to a solution," and "When I think of engineering, I think of design, like designing something which you are going to test out, and eventually you create a product." Therefore, when she applied engineering to her STEM project, she wanted her students to work through a project and to solve a problem by coming up with their own solutions. She stated that the engineering process was a tool to help her students do problem solving and to generate their own ideas. She said,

> STEM [integration] is an engineering way of thinking to come up with how I am going to solve this problem. Using the engineering process to create your own unique solutions to a problem is a key to STEM [integration] and kids should use STEM [integration] in school as a process getting to a solution.

Lisa felt that mathematics was also an important component in a STEM project because mathematics is another way to do problem solving. She said, "[Mathematics is] a way to solve problems that involve numbers." Therefore, she valued mathematics in STEM integration because mathematics gave the numerical aspects to STEM integration. She said,

> Math is very important to STEM integration. [STEM integration] needs a mathematical part to it as well. It is like getting [students] to think

> numerically as they work through the process. It is like if you are dealing with a science concept and it has a number with it. Math naturally falls into it because there are numbers in science all the time.

Although she believed mathematics was an important part to be integrated into a STEM project, she was convinced that sometimes in life science there was no room to integrate mathematics. For example, her Genetic Engineering project, which she considered a STEM project, had no mathematics involved. She said,

> My kids have learned Punnett Square and predicting probability in my gene unit, but I didn't have them using Punnett Square in the [Genetic Engineering] project. I just think [Punnett Square] really cannot fit into the Genetic Engineering project, or I just need to find other ways to make it fit.

However, that did not mean that she never tried to integrate mathematics into her STEM project. She had previously taught a STEM project in one of her ecology lessons where students needed to come up with a mathematical model to predict populations of pelicans to help biologists maintain the balance of an ecosystem. Therefore, to Lisa, adding mathematics into her STEM project was really dependent on if using math would make sense to the science content that she wanted to teach.

As for technology, Lisa defined technology as "using human-created inventions to enhance or to experience something." She gave the following example to describe her view of technology, "It is like a kid using a microscope to see something he could not see before. The kid is using technology to have an experience that he cannot have without technology." One interesting aspect was that Lisa was not particularly concerned about using technology, especially the Internet, in her STEM projects. She provided two reasons to explain why technology was an additional component in her STEM projects.

First, she believed when she asked her students to design a process, a product, or a solution to a problem, she was asking her students to design a technology. In other words, she was integrating technology into her STEM project by asking students to create a technology. Second, she preferred not to use the Internet in her STEM projects because that might hinder students from using their imaginations and creativity. She stated,

> When STEM emphasizes imagination and creativity, it is kind of challenging not feeding [students] too many examples. They just want to use one of [the existing examples], not really thinking about their own [ideas]. Since I want them to create their own ideas rather than copy one that is already in existence, I think that not having [the Internet] available almost made them think more creatively. If they go to computer lab and see genetic engineering ideas, they may be tempted to pick one of them for their project, rather than coming up with their own idea. If they do that, they are not really using their own problem solving and creativity. They just copy someone else's ideas.

Learning outcomes for students when using STEM integration. One of the major goals for Lisa's STEM projects was that students could be independent thinkers by using their own thinking to solve a problem. She felt that her students were not familiar with working on an open-ended question that does not have a correct answer. She said, "When I do STEM integration, I find students get much more frustrated because they have [previously] been given a very concrete set of directions like 'do this' and 'observe this' for a long time." She was convinced that generating their own solutions to solve a problem was a skill that her students constantly needed to work on. She elaborated, "They need to work on the skills like creating their own methods for solving a problem instead of using a method that has been given to them," and "When you do STEM integration, not everyone's solution is the same. So that frustrates [students] because they think they are wrong." Generating ideas to solve a problem also helped her students to establish individual ownership for what they have learned. She recalled some of her STEM projects and said,

> [Students] got mad at first because I didn't necessarily tell them exactly what to do. I just gave them some rough directions. But at the end, they were really proud when they realized, 'Oh, I came up with an idea that no one else thought of in the whole class and it worked'. [STEM integration] gave them a kind of self-competency to think outside the box, and the ability to really just create their own products.

In addition to that, Lisa also believed that STEM integration provided a learning environment that connected with real world problems. Therefore, another goal for her STEM project was giving students an opportunity to apply their knowledge in real life situations. She said,

> [STEM integration] makes [students] understand the concepts that had been taught in class on a different level than just reading about them. It is like how you solve a problem in real life by using the content knowledge that you have. STEM integration engages students in thinking about more real world aspects. It gives them opportunities to tie something in a real world.

Lisa also wanted her students to be aware of the ethical issue in real life situations. She considered this an important aspect that she should bring up when she taught her Genetic Engineering activity. She said, "[Students] have to talk through some questions, such as is this [GMO] really a true benefit to society? They have to really think about it because they are messing with genes."

Life skills. Lisa also considered independent thinking to be a life skill that her students needed to master, even beyond a science classroom. She said, "STEM integration is teaching kids about a process. It is like life skills—dealing with a problem and dealing with their frustration. [STEM integration] is working through their frustration level." She recalled that some of her students were really upset at the beginning of her STEM project because they were not familiar with the process. However, at the end of the project, her students were really proud about what they had accomplished.

Models of implementation of STEM integration. Lisa stated that how she used STEM integration was really dependent on how it fits with the topic that she wanted to teach. Teaching STEM integration also needed to address the science and engineering standards. She said, "I look at a topic that I want to teach. Then I think if I am going to put STEM integration into it or not," and "STEM integration is like a tool for me to use to engage my students' learning for whatever I can fit in my topic." Therefore, the length of her STEM projects could be a couple weeks or just 1 or 2 days long. For example, she had done a 2-week-long zoo STEM project. During the project, students needed to create a model exhibit for animals. She said, "[Students] actually use the engineering design process and work with scaling to draw blueprints. [The zoo project] has biological problems and how could we make this animal happy and content in this habitat. It meets a whole bunch of the standards." On the other hand, the length of her genetic engineering STEM project was only 2 days. The purpose of her genetic engineering STEM project was to give students a sense of what genetic engineering is and what genetic engineers do for their job. When she compared these two STEM projects, she said,

> With genetic engineering, it is part of a big genetic unit. I just want to use that project to introduce what genetic engineering is to my students. Whereas the zoo project, I feel I can touch on a lot of aspects of ecology when we make a zoo exhibit. So, [the zoo project] just fits better to the entire unit. I can use that project through the entire unit.

Issues or difficulties in implementing STEM integration. Lisa articulated five concerns or difficulties in planning and implementing STEM integration. First, she was aware that in life science it was hard to do some parts of the engineering design process. Second, she was concerned about how much scaffolding her students needed to complete a STEM project. Third, she believed her students' reading and mathematics skills had an influence on how she designed her STEM projects. Fourth, she had challenges to control how much time her students needed to complete a STEM project. Finally, Lisa expressed concerns that the fun part of her STEM integration lessons took over from the intended learning.

How to implement STEM integration in different subjects. One of the biggest difficulties for Lisa in using STEM integration related to life science. Lisa believed that the engineering design process was a major focus for her STEM integration lessons. However, in life science, Lisa felt it was difficult to fully use the engineering design process. She pointed out that in life science, especially at the middle school level, it was hard to do the testing phase and redesign phase when she used the engineering design process in her teaching. She stated,

> The one thing that I struggled with in life science was the testing phase. It felt like some part of the engineering design process was missing [in life science]. That might be just that the nature of life science was difficult to truly test things.

She usually asked her students to create a plan or a process rather than to create an actual product, which she perceived as a limitation in her STEM projects. Her Genetic Engineering activity was one of the examples that confirmed this difficulty. She asserted, "In life science often students are not necessarily designing a product, but maybe a plan.

We are not actually genetically engineering anything. There is no way for us to really create a genetically modified organism." Therefore she conducted a discussion with her students at the end of her STEM projects instead of testing and redesigning their final products. She said, "I have to modify the part of the engineering design process that we cannot actually do. Instead of doing the testing phase in an engineering design process, we do discussion at the end."

How much scaffolding do my students need? Lisa was convinced that her students needed more guidance and directions at least at the beginning of a STEM project. She felt in order to complete a STEM project, students needed to do and to remember lots of steps like a science lab. Yet, a STEM project was not like a science lab that had clear directions for students to follow. Because STEM projects were not structured at the level of the science labs that students normally did, they encountered difficulties in completing the STEM projects. Lisa believed that was because students had no idea of what to do or where they were in the engineering design process. She said,

> The multisteps process is a challenge for seventh graders. Students are not familiar with too many step projects. I think [the STEM project] was not structured enough for a lot of kids. In science labs, we always do the same thing—follow the directions step by step … [The STEM project] is a little chaotic because [students] are not exactly sure what stage they are supposed to be on.

Therefore, at the beginning of a STEM project, she was convinced that she needed to be very clear about what her expectations were with her students. She said,

> I think I need to do a little more hand holding as I introduce [students] to an activity like this. Just making sure they are clear on what stage they are at as they are going through the process. If I don't do that, they may get lost and won't really know what to do next.

Lisa believed it might be better to teach a STEM project step by step rather than just throw a whole project at the students at once. In other words, using a guided process, step by step, was a much better way for her to teach STEM projects. She recalled her experience of teaching the Genetic Engineering activity and said,

> Maybe next time, rather than introduce the entire assignment at once, I will have them working at their own pace, step by step. I think if I am going to do this [genetic engineering activity] again, I may have [students] type up or write up their descriptions on how they created their genetically modified organisms step by step. I think maybe that is kind of a neat option.

Students' abilities. Lisa believed that not only did her students need more guidance in completing the STEM projects, but also their reading and mathematics skills were other important factors that challenged her in planning and designing the projects. The students' reading skills particularly shifted her decisions on how she could use computers (technology) in her STEM projects. She said,

> If I just said, 'OK, Google genetic engineering', [students] will get all these things and they will just end up taking a lot of time. I don't know if that will be really useful if I use computers in that way. Most of them are not super fast readers. It is just very time consuming.

Therefore, she stated that she needed to narrow down to only a few websites if she wanted her students to do background research through the Internet. She said,

> I find with Internet research, giving [students] a broad topic, such as genetic engineering, they are just going to get overwhelmed with so many different websites and options. The best way is to give them only some websites that they should go and search for the things that they need.

She was also convinced that her students' mathematical skills were another challenge. She said "I think [STEM integration] makes [students] use mathematics skills that are really challenging to them. I think some of the kids just don't have the mathematics background.” Therefore, she believed that in order to do STEM integration, students needed to have a certain level of math skills. She said,

> [Students] haven’t had to think through how to use the engineering design process. They need to think about their own way to come up with a solution. The more mathematical knowledge you have, the more you feel comfortable manipulating numbers. The more you can understand the meaning of integration.

Time. Lisa believed her students needed more time to understand a STEM project, because students needed to come up with their own ideas. This could be traced back to why Lisa believed a better way to do STEM integration was to provide very structured instruction to students. In a regular science lab, Lisa could easily plan how much time she needed to teach it. But because students needed more time to figure out what they needed to do without many instructions in a STEM project, it was more difficult for Lisa to plan how much time they would need to complete a STEM project. She said,

> To me, time is always the challenge. [Students] may need a longer amount of time than I want them to take. It takes longer to do STEM integration. You just have to plan for that. You just have to keep that in the back of your mind, ‘This is going to take a while’, because the process is more challenging.

In addition to that, Lisa had trouble keeping all of the students at relatively the same point in the process. She said, “Keeping the project moving along at a pace that makes sense without having too many kids finish early and have nothing to do is my challenge.” She confronted this problem when she taught her genetic engineering activity. The students who finished earlier walked around the classroom and talked to others. They disturbed other students who were still trying to finish their project.

Fun vs. learning. Lisa expressed concerns that the fun part of her STEM integration lessons took over from the intended learning. In her Genetic Engineering activity, students did not carefully fill out all the information and notes that they needed to do for the project. She said,

> [Students] don't want to go slowly, carefully working through their ideas. They don't want to spend time to share with someone about their ideas. They don't want to talk about the strengths and weakness of their products. They like the hands-on part, such as drawing their posters and building their genetically modified organism. But, a lot of them sort of just skim over the parts that ask them to evaluate their ideas with others. Students so often want to just be done after they finish their posters.

Other. Lisa believed her students loved to do STEM projects, because they were really engaged. She also believed that helped students to learn science. She assumed the high engagement level was because STEM integration gave students a sense of their own learning. She said,

> [Students] like it. Their engagement levels are higher. I think this helps engage kids to get exciting about the science lesson rather than just doing the same experiments that everybody else is doing. It [STEM integration] allows kids to get more engaged in what is happening, because they are ultimately responsible for the products at the end. It is like do your own thing, and try out the idea that you have. I think [STEM integration] gives them kind of a sense of pride that this is my invention.

Carolyn

Carolyn loves being able to focus on making science both accessible and fun to early adolescents. She believes that the classroom should balance opportunities for students to construct their own knowledge with some direct instruction of key concepts. She wants her students to learn how to learn. She also wants her students to understand how the things they learn about in school connect to their lives.

Structure of the STEM Integration Class (Candy Bag Activity)

This case focuses on the Candy Bag activity that was taught by Carolyn. This activity focused on building a candy bag and was based on a 5-day lesson plan that was implemented in a sixth-grade physical science class in School B. Each class period was 45 minutes, and there were 24 students in the class. The activity was observed at the end of October, which was the beginning of the school year. As a result of the activity, Carolyn wanted students to develop an understanding of (a) the engineering design process, (b) teamwork in the design process, (c) making and testing predictions, and (d) product design challenges. The following are details of each day of the Candy Bag activity.

Day 1. Day 1 had two goals: to review the engineering design process and to conduct candy bag background research. At the beginning of the class, Carolyn said to her students, “This is an engineering project. You are going to design and build a better candy bag.” She asked students to work in groups of two and let them choose their own partners. However, she did not let her students choose their partners until the end of the class. She wanted her students to know what they needed to do for the project before they chose their partners. She also wanted her students to keep notes for this project. She asked them to open their notebooks and write down the date and the title of the project, “Design and Build a Better Candy Bag.”

Conducting background research on candy bags was one of the goals for the day one activity. Carolyn said to her students, “Do you remember when we talked about the engineering process, we said one of the things an engineer does is to go find out what other people have already done?" Carolyn emphasized the importance of doing background research by stating, "So maybe [students] can copy the ideas and make them better," and "We don't want to start from scratch every single time." She asked students to think about the engineering process that they had learned about last week. She said, "We start with 'What is our challenge?'" She asked students to write down the challenge—*to design and build a candy bag that will hold the most candy without breaking or spilling the candy*—in their notebooks. She said, "I give you the challenge. Now, how have others solved this problem?" She gave students an article about the inventor and history of paper bags and asked the students to read it. Then, she asked her students to recall some of the facts from the article (Appendix D).

In addition to having them read the article, Carolyn wanted her students to have a direct experience with different candy bags. She divided the students into groups of four and gave a variety of bags to each group. She asked the students to examine and describe the bags and to identify good and bad characteristics for each bag. She provided some examples of what qualities to look for in each bag by asking, "Is it easy to carry?" "How much can it hold?" and "Is it attractive?" She told them to write down "any sort of thing that you can think about the bags." She asked students to write down their observations about the bags in their notebooks.

After students examined the bags, Carolyn asked each student to share their thoughts with the entire class. A student said, "The good thing about my bag is the handles. The bad thing about my bag is it may suffocate you." Carolyn replied, "Because [the bag] is made of plastic, it was a little bit dangerous, but reusable." Another student said, "The bad thing about my bag is that it cannot fit a lot of things in there."

Then Carolyn reminded the students of the challenge written on the whiteboard. She connected their brief research on candy bags back to the design challenge by saying, "You have learned that materials that you use to design your bag will determine the strength of your bag by doing your research," and "You can make [your candy bag] as big or as small as you want. I hope you have some ideas about what's good about a bag and what's bad about a bag."

Day 2. At the beginning of day 2, Carolyn introduced the procedures students would follow for the next 4 days. She showed the worksheet (Appendix D) to the students and told them, "This is what we are going to work on today. You are going to build a prototype of your candy bag." Then she said, "The other half of the worksheet is the budget sheet. This is where you are going to keep track of what you are actually buying." She told students that she would put her signature on the materials that students wrote down on their worksheet and that they would not get the materials twice without paying. Before she showed them the materials they could buy from her, she said, "For the engineering project, you are going to have some criteria and restrictions. For example, we don't build an airplane without goals." In her Candy Bag activity, there were three constraints that students needed to adhere in order to build their candy bags. First, students were only allowed to use materials that Carolyn provided, such as plastic sheets, masking tape and twine. Second, the candy bags needed to have handles. Third, students needed to build their bags without exceeding the budget. Carolyn explained that each student had a budget of $200 dollars for the initial design and another $200 for the redesign. One of the students asked about bargaining for supplies, and Carolyn replied, “No. You get what you get.” Another student asked, “Can you get a refund if you grab the wrong things?” Carolyn said, “No, you need to plan it very carefully. The company that sells you the materials will not do exchanges.”

Before students started to draw prototypes of their candy bags, Carolyn told them, “You are going to have your design ready to show me [on the worksheet]. It has to be reasonable and needs to be labeled,” and “I want details about your budget, like a piece of plastic that costs $100, three pieces of twine that cost $30, and five pieces of masking tape that cost $50. In total, my bag will cost $180.” She also told the students that if they needed more supplies and they still had money, they could come back and buy more. A student asked about going over the budget, and Carolyn said, “If you go over your budget, I will not give you the supplies.” Another student asked about buying supplies in a smaller size to save money, and Carolyn answered that all of the supplies come in one size only so students would need to cut it out of their budget and design if they could not afford it.

When students started to design their candy bags, Carolyn walked around helping them and answering their questions. She said, “If you need to take a look at the supplies before you start to design your bag, you can come to me and I will show you them.” She also reminded students that they should think about the dimension of the bags. In her Candy Bag activity, the size of a piece of the plastic sheet was 20 cm by 30 cm and cost $100. In other words, if students wanted to buy two pieces of plastic sheet, they would not have any money left to buy other supplies. She explained further to the students, “When I said it needs to be labeled, I need you to show me how wide and how tall your bag is. Obviously, no side can be bigger than this [20 cm by 30 cm].” She also gave them a hypothetical example by stating, “Frankly, [the bags] probably need to be smaller than this [20 cm by 30 cm]. Because if you buy two pieces of plastic, I am not sure how you are going to hold them together.” Then, she folded a piece of plastic sheet in half and said, “You can do this, like 15 by 20.” When Carolyn walked around, a group of students asked her about an idea for their candy bag. They wanted to build a candy that was sticky on the outside, because they believed in that way their candy bag could hold candies both inside and outside. Carolyn replied, “I probably don’t want a bag to be sticky all over the outside. Yes, it can pick up candies, but it also will pick up other things, too, like dog hair.” The students said, “Yes. That is gross.”

Day 3. Carolyn started day 3 by reviewing what students needed to complete on their worksheets. She said, “Some groups have finished their diagrams. In order to get supplies from me, your diagram needs to show the details of each part,” and “In this budget sheet, you need to write how many, how much [the supplies] cost, and the total cost.” Carolyn made sure students understood that both partners needed to have the diagram and budget sheet ready in order to pick up their supplies. When the students were ready, they lined up to pick up their supplies. Carolyn checked each student’s worksheet before she gave out supplies to that student. Some groups were sent back because there were some errors on their worksheet. Most of the groups that had been sent back to redo their work did not have details on their drawing or had labeled the wrong dimensions. For example, one group did not have details labeled on their drawing. She said, “This [she pointed to the drawing] should show how long this side is and how long that side is. And I need you to label what materials you are going to use, like tapes or plastics.” Several groups did not label the dimensions of their drawing. Carolyn would then explain that she needed dimensions for the different sides. She told one group, “Because it is 20 by 30, your design does not work. A piece of [plastic sheet] is 20 by 30.” Then, she demonstrated the size of a 20cm by 30cm sheet to the students. Next, she said, “Unless I give you two pieces of [plastic sheet], it can’t be 20 by 30. So go back and figure that out.” She also showed students how to correct their errors by folding a piece of plastic sheet in half while explaining, “See, if you do it like this [she folded a plastic sheet into half], it would be 20 by 15. You need to go back to fix it.” Students who had wrong scales labeled on their diagrams also had been sent back to redo their work. For example, she said to a group, “I don’t think you mean 2cm by 2cm, because that would be this big. [She used a ruler to demonstrate 2cm length to students.] Do you mean this big?” The students indicated that that was not the size they meant to write. Students who did not complete their worksheet also had been sent back to redo their work. For example, a group did not have their drawing, so she told that group to complete it before she would sign their sheet.

Carolyn was busy with students who were struggling with their worksheets, while other groups started to build their bags. After they finished building, they started to test how much weight their bags could hold by using triple beam scales and spring scales. Instead of using real candy, students used marbles to test their candy bags. It was very obvious that some students really struggled to complete their worksheets, while other students easily completed their prototype designs and budgets.

At the end of day 3, Carolyn was concerned about how students should measure the volume of their candy bags. She told the class, “Unfortunately, many of your bags are sort of in weird shapes. So, we are going to [measure the volume] in a different way. It is different when you measure something in three dimensions.” She showed students how to measure volume by using a tissue box. She explained, “If you have a box shaped bag, you do volume by multiplying the length times width and times the height of your box.” She took a candy bag and demonstrated, “I can measure this direction [the length of the bag] and this [the height of the bag] pretty easily. It will be harder to figure out this [She used a ruler to measure the width of the bag’s bottom].” After she measured the bottom she said that it was zero and asked the class what happens when zero is multiplied and they correctly replied. She said, “You can measure the length and height of your bag, and maybe multiply a half centimeter of the width of your bag to get an approximate volume.” She told the class that they would not use water to measure the volume. Instead the students would count how many pieces of candy they could fit in their bag. As for the weights, Carolyn wanted her students to think about the math they had already learned that could help them measure the weight of their candy bags. She reminded them of what they had already learned in an earlier lesson and recommended that they go back in their notes to see how to measure weight and mass. She emphasized that students should use what they already know to think about how to predict and measure the volume and weight.

Day 4. Day 4 was the testing phase for students' candy bags. Carolyn explained that once their bag had been tested they would then do the redesign. She wanted students to work together and talk to their partners about what was good and bad about their bag. Students were then told to discuss the changes they could make for their redesign. She also wanted students to think about the design of their bag. She said, "Maybe you have a bag that is really strong, but really small. How can you change your design to make it hold more?" and "Maybe you built a bag that is already perfect—can you rebuild it?"

Before students could test their bags, Carolyn wanted them to predict the estimated volume of their bags. She explained, "You are going to do this by looking at the length times the weight times the height of your bag [She wrote the equation $V=l\times w\times h$ on the whiteboard]. That is going to be cubic centimeters [cm^3]." On day 4, students did not use candy but instead marbles to test their candy bags. Therefore, Carolyn asked students to estimate the total weight instead of how many candies their bags could hold. Students were required to record their predictions about the volume and the weight on their worksheets.

Carolyn wanted her students to record the actual weight when their candy bags broke. She described what she considered a breaking bag, such as the side popping open or the bottom ripping out. Then Carolyn showed students how they could test their bags by using a spring scale and a bag that she had made earlier. The spring scale she used could only hold 500 grams. She told the students, "If you have a strong bag, [a spring scale] might not work. You will need to take all the weights out and use a triple beam scale over there to get the total weight." Before she sent her students off to test their own bags, she made sure they knew what they needed to do by telling them to estimate first and then see how much weight their bag actually held.

Some groups had difficulty finishing their design and Carolyn was busy helping them. Other groups started to use either spring scales or triple beam scales to test their candy bags.

Day 5. Carolyn started the day 5 class by checking students' worksheets for four things: the estimated volume and weight, and the actual volume and weight of their bag. She had a poster that served as a data table where students could write down the number and mass of candies that their candy bags held. Then some students started to test their second candy bag (the one that was redesigned). Other groups still worked on building their second bag.

The students were excited to test their bags. After they were finished, Carolyn asked them to present their bags and to describe what they would do if they were asked to redesign it again. Most students thought that they needed to build stronger handles and also make their bags bigger in order to hold more candies. For example, one group said, "I really like my bag, but if I am going to redesign it, I will make the handles stronger." Another group said, "I am going to make my bag bigger to hold more candies."

Interview Results

Carolyn's view of STEM integration. According to Carolyn, STEM integration is "whenever more than one of the STEM disciplines are used together." As long as she could integrate two STEM subjects, she considered it STEM integration. Based on this definition, Carolyn believed that she frequently used STEM integration in her class, particularly in integrating science and engineering. She stated, “For pretty much every scientific concept that we covered, we did some sort of engineering project,” and “I took something we already did and found out how I could give it design parameters to make it more related to engineering.” Carolyn provided a strong argument for her view of STEM integration. She believed a teacher could not find a lesson plan or an activity that had a perfect balance of the four STEM subjects. She believed science teachers would focus on science more, but mathematics teachers would focus on mathematics more in a STEM integration lesson. She stated, “[Science teachers’ lesson plans] were definitely heavy on the science piece, because we were doing [STEM integration] in science classes. If I were a math teacher, I would be hitting on the math part much harder.”

The priority for her STEM integration lesson was science concepts that were addressed in the sixth-grade science standards. After she determined the science standards that she wanted to include in her lesson, she thought about how she could add engineering concepts. As she noted:

> I start with the science concepts that we are covering, because sixth grade has these benchmarks that need to be hit. Then there are the big ideas about how you could tie this up with engineering. How can we make some sort of product? … [STEM integration] does feel like here we are doing a bunch of science and here is some engineering to go with it.

Carolyn believed there were a lot of overlapping areas in science, engineering, and mathematics within physical science. She considered measurements and calculations needed in the lesson to be where she integrated mathematics. As she commented,

> The science and math pieces together happen all the time in physical science. We do measure things, and we make graphs and analyze data that way. For example, because it is physical science, we measure speed and make graphs. So that piece [math] piece is kind of given. And engineers

> also have to measure and calculate things too. When [students] test things, they need to use data to evaluate things. So it gives that quantity piece to it.

Although she believed mathematics had a lot of overlap with physical science and engineering, she was not particularly concerned about integrating mathematics into her STEM integration activity. She said, “As for the math piece, I don’t usually consciously say how I am going to integrate math into this [STEM integration activity]. If some of the measurements make sense, we do quantitative work,” and “Mathematics is kind of everywhere. It is like a tool to help.”

Carolyn defined technology as “lots of cool gadgets and we use it as a tool. [Technology] makes life easier.” If she can integrate technology into her lesson unit, it is great. Yet if there was no technology in her STEM lesson unit, she felt that was fine with her, too. She said, “As for the technology, I will say it ends up just being integrated into all of those other pieces where it applies.”

Another central idea for Carolyn related to STEM integration was as a teaching strategy. She believed that STEM integration was a strategy to engage students to learn science and to make learning more personal to students. The aspect of the application of STEM integration helped her students internalize and reinforce the science concepts that she wanted to teach. She said, “So [STEM integration] just gives another way to look at the science that we are doing, and gives [students] chances to be more part of [the science],” and “I think [STEM integration] gives [students] a chance to show what they already know and reinforce the concepts.”

Pedagogies needed to achieve STEM integration. Carolyn's STEM integration lesson focused on science and engineering. She believed it is important to integrate science and engineering into her teaching. On the other hand, she considered math and technology to be additional pieces in her STEM integration lesson or unit. Carolyn provided four reasons why she focused on science and engineering in her STEM integration lesson. First, science and engineering share a lot of common aspects. Second, engineering is part of the Nature of Science and Engineering standards that she is required to teach. Third, engineering provides a context as the application of science content that helps her students use science in a different way. Finally, integrating engineering into science engages her students in learning science.

Carolyn considered that science and engineering used very similar processes, as she stated, "You are defining a problem and you are trying to solve the problem, and the idea of testing things and using results—those are the sort of the areas where science and engineering really overlap." Carolyn also commented that integrating engineering into science was part of her job, because of the sixth-grade science standards. As she commented, "[Engineering] is one of the sixth-grade standards. We have no choice. I am [teaching the engineering process] sort of for the sake of the standards."

Integrating engineering into science provided two valuable outcomes for Carolyn's students. First, integrating engineering created a place for her students to apply scientific concepts. Second, integrating engineering helped engage students in learning science. Carolyn did not separate these two outcomes because she commented that the application aspect of engineering was also the fun part that engaged her students in learning science. As she noted,

> Integrating engineering with science is really fun for [students]. I think it also gives them more realistic pictures. The engineering piece is a way we are kind of able to make [science] fun. [Integrating engineering] does engage them. They are super excited when we do [engineering] projects.

Carolyn provided two reasons why she considered mathematics and technology to be optional components in her STEM integration lesson. First, her students' ability to use mathematics and technology was the most important factor that influenced her decision if she wanted to integrate mathematics and technology. Second, her school did not have enough high-technology resources, such as computers, for her to use in her teaching.

Carolyn believed that sixth graders did not need to know very complex mathematics. She stated, "For the sixth-grade level, [students] are still using very basic mathematics, such as how to work with fractions and decimals." Therefore, she believed the math concepts that could be integrated into her STEM lesson were very limited as she noted that at the sixth-grade level, a lot of the mathematics the students learn is procedural skills and symbolic manipulation. In her Candy Bag activity she asked students to measure and calculate the volume of their bags. When she reflected on her Candy Bag activity, she said that most of her students had a hard time doing these measurements. She stated, "Measuring or calculating volume is not something [students] are really confident with in the sixth grade anyway." In addition, she noticed her students expressed feeling overwhelmed if she put too much mathematics in her science class. She said,

> We have students where it seems really basic math, and yet it is something that they need constant reinforcement on. They all say, 'Why are we doing so much math? I thought this is a science class.' I guess that really is where math ends up in my class.

In fact, in her STEM integration lesson, she approached mathematics as a tool rather than a concept that she needed to teach. She said, "For me, it is more of an added bonus to get some math in here, rather than I have to teach this math concept."

In Carolyn's classroom she only had access to basic technologies on a regular basis. She explained, "I have old-fashioned technologies, such as rulers and triple-beam balances, but not high technology, such as digital devices and computers." She was convinced that was the way it should be and believed that in the sixth grade there was no need to use sophisticated technologies. She said,

> In sixth grade, the levels [at which students] supposedly understand things do not necessary require [high technology]. For example, what sixth graders need to understand is that if you increase potential energy, it [a car] will go further and faster. They don't need to calculate the velocity at this time. They don't need to do things that need more sophisticated technology. It would be ridiculous to complain that we don't have high technologies. It would not make any sense if we asked our school to spend a million dollars to buy high-tech gadgets for sixth graders.

On the other hand, Carolyn was also convinced that there was a huge range of technology abilities amongst her students. Carolyn referred to technology equivalent to computers. Her students' computer abilities also had an influence on her decision not to incorporate computers as part of her STEM lesson. She said, "We have to teach [some of] them how to type. So how much we can use [computers] in a science classroom is really dependent on how we can meet them where they are."

Learning outcomes for students when using STEM integration. Understanding scientific concepts and the engineering design process were the two learning goals of Carolyn's STEM integration lesson. In fact, her ultimate goal was for her students to understand and to be able to use the engineering design process. She said, "I think that the cyclical nature of [the engineering design process] is really important for them." Therefore, she wanted to integrate engineering into science concepts that she teaches throughout the entire year. She explained,

> My plan is that for every big scientific concept that we cover this year, we will have some project toward the end of the unit that has a culminating engineering project. So [students] can apply the scientific concepts that we have been doing in an engineering situation.

Although she believed that science and engineering share a lot of commonalities, she also believed it was important that her students could distinguish the differences between science and engineering. Therefore, helping her students understand the difference between science and engineering was another goal for her STEM integration lesson. She stated,

> When I introduce the idea of engineering to students, one of the things I talk about is the difference between science and engineering. Scientists are maybe doing the research just for the sake of doing the research, whereas engineers are doing this with a goal in mind. I think over the course of the year, looking at the big question of how are scientists and engineers the same and how are they different, coming back to that over and over again as a higher level thinking piece with students.

This goal was also embedded in the Candy Bag activity. Carolyn said in the interview that,

> [The goal of] this [Candy Bag] project is that [students] are not just trying to find "OK, how much can it hold?" We want to find at the end a bag

> maybe holds lot of mass, but does not necessary hold our candies, which is the goal.

Life skills. Carolyn believed the redesign part of the engineering design process served as an important life lesson for her students. She asserted that it was really challenging for a sixth grader to learn from his or her own failures. She said, "[Students] are not used to thinking creatively and dealing with failures. That can be a real challenge to keep them motivated when things weren't going right." Therefore she affirmed that the redesign part in an engineering design process helped students understand the importance of endurance and persistence. She said,

> I think that [learning from mistakes/failures] is a good life skill for them, not giving up and understanding that it is OK if it does not work out this time. [Students] need to know and have to be willing to do the engineering redesign piece, such as it is OK that it has a result that is not what you expected. It is OK to try and to fail because you learn from your failures. That is true in science, too. [A STEM project] gives [students] good life skills in terms of not giving up.

Models of implementation of STEM integration. Carolyn felt that in general, how teachers used STEM integration depended on their learning goals and also their students' abilities. Thus, she assumed that her STEM integration lessons could look very different from other teachers' STEM integration lessons. She explained,

> I am a middle school science teacher, so [the Candy Bag activity] is what I do for STEM integration. My students needed a lot of guidance to do the project. If I am a high school teacher, I will give my students more freedom to do the project. It really depends on who and what I am teaching. So, I think math teachers may have different STEM integration ideas as compared to science teachers. A high school teacher may have very different ways to do STEM compared to a middle school teacher.

Carolyn mostly used STEM integration lessons as culminating projects to engage her students in learning science. In addition, she also wanted to connect the science concepts that students had learned in her class in her STEM integration lessons, too. She said,

> I think I mostly use [a STEM integration lesson] as a way to let [students] show some of the science they have learned in a way that is really fun for them. At least a couple of them that I had done in the past as culminating projects are not emphasizing engineering but emphasizing science content.

During the interviews, Carolyn mentioned one of her favorite STEM integration projects, building a roller coaster. The project asked students to design, test, and improve a roller coaster by using the engineering design process and science concepts, such as Newton's laws, that they had learned throughout the year. Carolyn reflected on the project and explained that the students were very engaged in the project and eager to try different things and make it work. She also noted that this project was a way to engage students who weren't always engaged in their schoolwork.

Issues or difficulties in implementing STEM integration. Carolyn articulated four concerns or struggles in planning and implementing STEM integration. First, she was concerned about the level of open-endedness in her STEM integration projects. Second, she was constantly aware of how much time she could allocate to a STEM integration project. Third, she struggled to balance the fun part of her STEM lesson units, such as building a project, with maintaining student focus on the academic part of the project, such as drawing prototypes and completing worksheets. Finally, she was not satisfied with the way that she integrated math into some of her STEM lessons and was not sure how to integrate it in a better way.

How much scaffolding do my students need? One of Carolyn's dilemmas when using STEM integration was how much scaffolding her students needed in order to complete a STEM project. She said, “I think one of the things that I was really struggling with last year was how much scaffolding [students] needed so they could be successful.” Furthermore, she stated, “I think in terms of making them able to actually to do things well, it takes some scaffolding at the start of the year.” Therefore, Carolyn always took her students’ abilities into account when she planned her STEM integration lessons. She was particularly concerned about how open-ended or teacher-directed her STEM lessons should be in order to meet her students’ abilities. She said,

> [Students] needed a lot of directions. If we make a project fairly open-ended, a lot of students are really not ready for that yet. I have some students that can do [a fairly open ended project], but it seems like we have a lot who are really struggling with them. I felt like what you can do for STEM integration partly depends on where your students are.

This showed in her Candy Bag activity. Some of her students finished their candy bag design within 1 hour. However, some of her other students needed to spend at least 2 days to finish their prototype design.

Time. The amount of time that could be allocated to a STEM integration project was another big concern for Carolyn. She said,

> We don’t have 3 months to do a project. I think the time limitation is just a huge piece. We only have 44 minutes for a class. By the time [students] settle down, I really don’t have a lot of time to do [A STEM project]. The schedule of the school days can be really challenging. We don’t have enough time. We have to move on. We have too much that we have to cover.

Therefore, Carolyn needed to adapt her STEM lesson to fit the time constraints of her class. She said,

> We need a project that is reasonable for [students] to accomplish something in frankly very little time. Some of the projects we really need

> to narrow them down a little bit. If we could have an hour and a half, or 2 hours for a class to do a project, we might be able to think bigger.

Fun vs. learning. Carolyn also expressed concerns that the fun part of her STEM integration lessons took over from the intended learning. She believed it was hard for her to ask students to complete the not fun part of her STEM integration lessons. She felt sometimes the fun parts of a STEM integration lesson overshadowed the parts that students were supposed to learn. She said,

> The biggest [challenge] is getting [students] to do the 'not fun part', such as the documentation and the reflection. The other thing that is really hard is that they get so excited about some of the fun parts of the project. The measurement part is not fun to them. So, they do a very sloppy job on that. We do lab and that is fun, but they are not going to write anything down. Building a bag is fun, coming up with an idea maybe is fun, but actually drawing a diagram that has labels on it, and going back and thinking about it, these are not really fun.

About mathematics. Finally, Carolyn discussed her struggles with integrating math into her STEM lessons. She believed that STEM integration had great potential to provide a learning environment where her students could use their math skills in a real-world setting. However, she was also convinced that she did not do a good job of integrating math into some of her STEM lessons. She noted,

> Using [students'] math skills in a context, I think that is great. STEM can provide a real world setting for [students] to use their math skills. Everything ties with the measurements. I just feel that can be a really strong place to do math. However, I also feel sometimes it is really hard to use math in my class. Maybe I didn't connect to math as well as I could have.

For example, Carolyn was aware that she had not implemented the math component very well in her Candy Bag lesson. She said, "That [math] part in my Candy Bag activity, I always felt it was not very accurate. But I didn't know how to change it."

At the end of the interviews, Carolyn drew a conclusion for herself about the struggle of integrating math into her STEM lesson. She decided that if she teaches the Candy Bag activity again, either she will try to do her best to change the math part of the lesson, or she will just give up the thought of integrating math into her Candy Bag lesson. She said,

> [Integrating mathematics] really depends on what the activity is. Again, students' abilities play a very important role for this. Even just a simple thing like keeping their budgets in the Candy Bag activity, some of them really struggle with it. I wish I could figure out a way to modify the measurement piece, so [the math part] was easy enough for them to do. Or, maybe I should just not worry about [the math part]. Maybe I should just decide that [the math part] is not an important piece in [the Candy Bag activity].

Other. In addition to providing students with an opportunity to apply science concepts in a novel situation, Carolyn provided two reasons why she wanted to do a STEM integration lesson. First, to Carolyn, STEM integration provided a better opportunity for students to work collaboratively. In a STEM integration lesson, students have better opportunities to interact with other students, such as sharing their ideas. Carolyn said, "Some aspects of [a STEM integration lesson] pull pretty much everyone in. Kids really like it. The engagement level is great!" and "I really liked when students were sharing their projects, ideas, and working as groups together successfully."

Second, STEM integration lessons were memorable to students. Carolyn said, "I had kids from other years who said, 'Oh, you guys are doing candy bags again?' So I think that is cool. If you remember something I did a year later, then that tells me some aspects of it are definitely worthwhile."

Reese

While Reese was a teaching assistant in a university, she found out that she really connected with students and enjoyed the teaching aspect more than the research aspect. Therefore, she decided to become a teacher rather than a professor. While she is teaching she also works as a researcher with an active research lab. She believes it is extremely rewarding to be able to do both teaching and research in her career. She wants her students to see her as a “real” person and not just a teacher or nerdy scientist. She tries to get her students excited about science in general. As a teacher, she believes that she needs to help every student reach some level of success in a class, even if students aren’t very interested in the subject.

Structure of the STEM Integration Class (Genetic Engineering Project)

This section describes the Genetic Engineering project, which is a STEM integration unit taught by Reese. The project was implemented in an elective biotechnology class in School C. The class was made of up to 22 11th- and 12th-grade students and it was a 9-day lesson plan with 50-minute classes. The project was observed from the middle to the end of January, 2011. It focused on genetic engineering, conducting research, and ethical issues and culminated with a project presentation. During days 3 through 8, Reese let the students conduct their research on computers. Therefore days 3 through 8 had very similar classroom activities and subsequently this case only reports the significant events that happened between Reese and the students during that time.

Day 1. Reese started the class by introducing the Genetic Engineering project. She told the class,

> In your group, you are going to use your own idea for your genetically modified organism (GMO). The organism that you decide to modify has to serve a certain purpose. We are going to try to come up with an idea for a GMO that is going to solve a problem for our world or for certain people.

She talked about her expectations for the project and explained,

> I want you to be aware that this is a 100 points project. You will get a rubric later with how many points for each category. So you will know exactly what you need to do. In order to get a good grade for this project, you will need to follow what the rubric says to finish your project.

After she talked about her expectations for the project, she reviewed some GMOs that students had learned about in a previous class. She said, “Give me some names of GMOs, and why are they modified or what’s the problem or the issue that the creators tried to solve?” She called students’ names to answer the question. A student replied, “Mosquito…people try to modify mosquitoes for malaria resistance.” Another student answered, “Sweet potatoes in Africa. So they can grow better, like bigger, in bad soil.” A student said, “Papaya in Hawaii…for the purpose of resisting ring spot virus.” Reese said, “Some of the ideas that we have talked about are more beneficial to the world than others, right?” Then she asked students to take a poll of which GMO they believed to be the most important invention to the world. Students had different answers to this question. Reese said, “So now you know, what you think is important really depends on who you are and where you live and what you eat, so try to think about something or an idea that is important to somebody.” She put the project proposal slide on the interactive whiteboard and explained,

> You are going to determine a socially relevant goal for this Genetic Engineering project. You are going to say how and where you are going to put the genes into the organism and you are going to explain how you want the genes to be expressed; like, do you want the genes everywhere or do you want the genes only in the fruit? Also, you need to talk about the ethic issue for your GMO, like, will all people like your idea, will anyone disagree with your idea, or is there any risk to the environment?

Then, she gave the timeline to students and said,

> You are going to think about what you want to do and ask me questions like, if this is a good idea. By the end of the day tomorrow you are going to know exactly what you want to do. You are going to be in a group of two or three. You need to write a proposal paragraph to explain the issues that you will try to solve and ideas about how you are going to do that.

Then, she explained,

> Tomorrow, we will have computers out. You are going to start a Google presentation. You are going to ask questions and try to find the answers. After tomorrow, you will have another 5 days to do research on your project in the class. Then you are going to present your project.

Reese talked to the students about how to start their projects. She said, “First, you are going to think about a problem.” She showed an example presentation about a type of banana disease that was done by a group of students from last year. She said, “This group particularly wanted to find a disease resistance gene to save bananas from going extinct.” After she showed the PowerPoint presentation slides that were done by the group from last year, a student said, “That is a lot of work.” Reese replied, “Yes. That is why it is worth 100 points. I want you to come up with a new idea. That means you cannot copy something that has been done by scientists.” Then, she put the timeline slide on the interactive whiteboard again and said, “I want you to get into your group of two or three. I will give you a piece of paper and that is where you are going to write your proposal paragraph.” Then, she said, “The rest of the hour will be for you to think about what and how you want to do your project. Ask me questions. O.K., now get to work." She then passed out the project proposal paragraph paper to students (Appendix E).

Reese walked around the room checking in with students. A group asked, "We really don't know where we should start. We have too many ideas." Reese asked of the group to share some of their ideas. She then gave some recommendations and told the group to be sure to work together as a team and that she would check back with them later.

Day 2. Reese started the class by reminding the students what they needed to do today. She said, "By the end of the day on Friday, you have to have your project sent to me by email. I need to see something that looks like you have been spending a few days on it." Reese then gave students the project rubric (Appendix E) and said,

> So I gave you the outline that you need to cover. This tells you exactly what you need to do for your presentation and how many points it is worth. There are some categories that are worth more than others. I will maybe focus on some highest points, like ethics or how you are going to get the gene into your organism. Are there any questions for the rubric?

After she handed the rubric to students Reese walked around and helped students with questions. For example, a group had written, "Why do we need to save the oranges?" on the computer. The students asked, "So that is on quality...like you just gave a bunch of examples?" Reese said, "Yes. Like some reasons why oranges are important or why you would try to save them." A student asked, "So should I say what they [growers] do now and why it is not enough?" Reese replied, "Yes, like even what they do when it is still really cold…So just more reasons to justify your research." A group asked, "Do you think this is a good idea…if we want to prevent dairy allergies?" Reese explained, “A lot of scientists have done this type of work already. Before you jump into this topic, you need to find out what things have been done already.” Another group asked if their idea was good. Reese said to the group, “What kind of flower? You have to be very specific. It is a good idea, but you want to pick a very specific flower. Yes. It is a good idea, but just try to focus a little bit more.”

Reese also reminded students that they needed to hand in their project proposal paragraph with their group members’ names on it by the end of this class.

Days for conducting research. Starting with day 3, the students worked on their project as one group. During the research days, Reese did not give a lecture but instead walked around and helped students with their projects. Students were searching for information, such as research articles and gene sequences by using computers, working on their presentation slides by using Google presentation, and discussing their ideas with their group members. The following are conversation examples in which Reese helped her students with their questions.

Some students had a slide that said, “Where you will get the original DNA and basically how you will ‘grow’ and purify the DNA you need.” Reese asked them, “Where did you find it?” The group said, “PSR [sic]…whatever. Is this the sequence for…” Reese said, “Yes. That is the sequence for this DNA.” A student in the group said, “So we will take out the DNA…then…” Reese said, “Then, you set up a PCR reaction…” The group agreed and Reese said, “Then you make primers. One is here and one is there [pointing her index fingers together]…” A student said, “That is what I was wondering, how does this work. So, we based it on the sequence and make primers.” Reese told the group “to specify and to copy the primers.” A student asked how to do that, and Reese said, “You order them. You just tell a company that you want a primer that has this and this sequence, and then they sent it to you.”

Another group told Reese that they could not find the sequence that they wanted. Reese then told them a specific website to check and said, “Remember what we did in the class before? Yes. That is what you need. The sequence should be on the bottom of this page. There you go.”

Reese asked another group of students what they were trying to do. They replied, “The soil bacteria…it wouldn’t kill…” Reese said, “Did the article say what kind of toxin it is?” Then, she started to help the students look for more useful information about the bacteria from the Internet. The article had the title, “Cloning and expression of a toxin gene from Pseudomonas fluorescens GcM5-1A.” She told the group, “Let’s try this to see if we will have more choices.” She clicked one of the websites about Pseudomonas fluorescens WH6 and said, “You see how big the sequence is? That is the whole genome. We don’t want this…Let’s see if we can find a better way to do this.” She spent about 10 minutes with the group trying to help them find the gene sequence. Finally she said, “So, we don’t know what exactly the gene is. That is fine. We are just going to do more research on this one.”

A group wanted to do something with Zebra mussels. Reese said, “Are you hoping to just let this bacteria loose?” The students replied, “Scientists found out that you can just release them and it wouldn’t harm any natural mussel…the native mussels…and it wouldn’t kill any fish or any other thing either. It will just kill the Zebra mussels.”

Reese said, “So, this guy’s idea does not involve any idea of genetic modification at all. He just found the bacteria and released them. So, how can you use this idea with something that involves genetic engineering?” She gave students an example by saying, “Maybe you can try to put the gene in what [Zebra mussels] eat, right?” The students wondered how they could do it and Reese answered, “What you can do is…[Zebra mussels] eat algae. You can somehow take algae…so the algae have this new gene in them and that will make them sick.” The students then asked, “So, how you are going to produce it?” and Reese said, “You just have to transfer [the genes] into another lab.”

Reese checked one of another group’s slides and said, “You need to find what is causing that IGB response.” She started to help the students with their research. Reese typed “Dairy allergy” in the Google search engine and said, “What’s that protein for…Casein?” Reese said, “So what happened was you ate the products and your body makes IGB…So if you don’t have this protein, so your IGB stops to respond.” Reese asked if the students had used Google Scholar before and then demonstrated how to use it. She said, “A lot of results, so you guys probably will need to pick something, but we are getting close…here you go!” A student said, “So am I just going to copy this gene sequence to our slide?” Reese said, “Yes. Write this down, RNAi. That is what you use to shut that gene down.”

Reese walked to another group and said, “This looks like research about gene gun.” The students said, “Yes” and Reese replied, “That is really cool. So copy and paste this link to your reference page. So you will have it when you need it again.”

The group had the slide, “Effects of transformation” on their computer. Reese told them,

> You know what I will add? What will happen if you transform 100 plants? That is a lot of steps for your transform plan. I think I will use a gene gun. So what I will do is shoot the gene into 100 plants by using a gene gun, but that is what I would do. You guys maybe will have different ideas. So, maybe you want to add an alternative way to transform your genes?

Reese looked at another one of their slides, "Evidence to see if transformation is successful" on their computer. She said to them, "So you do a PCR transform plan to see if you got your gene actually in there…So do PCR again and then you put in the DNA."

Presentation Day

Reese started the class by telling students the order for their presentations. Then she said, "Everybody else needs to be absolutely quiet and pay attention to the group that is talking. If I see you working on something else I am going to take points off from your presentation." Then each group started their 15-minute presentation. If a student had a very soft voice, Reese would ask that student to speak up.

Interview Results

Reese's view of STEM integration. Reese believed a STEM integration lesson had to have at least three STEM subjects in it. She said "I think if you are going to call it STEM integration, you probably should have at least three of STEM. Just two, I don't really see to be a new thing than what is already there." The priority for Reese's STEM integration lesson was to address state standards. She was particularly concerned about integrating science and engineering into her STEM integration lessons. She said, "There are state standards that I need to follow. With the STEM integration, science is the most important part that I need to integrate. I also want to try to integrate engineering aspects." One of the biggest reasons that Reese believed her Genetic Engineering project was a successful STEM integration lesson was because she tried to integrate both science and engineering. She said, "I felt like because I am emphasizing the engineering aspects and then that is why I made this [the Genetic Engineering project] activity a STEM integration project."

Reese believed science and engineering were highly related to each other. When she defined science she said, "Science is a class where kids learn some facts, but [students] were more learning about a process in a way of thinking. They learn to think critically and always ask questions." She described engineering as "very tied to science, very process orientated." She felt that in order to do engineering, students needed to focus on refining ideas, coming up with a problem, and then trying to solve it. Also like science, engineering rarely has only one solution. When she integrated engineering she wanted students to recall things that they had already learned. She said, "The idea of engineering, I always ask kids, 'What could we have done better? If you do this again, what are things that you could do to improve it in some way?'"

Reese considered that math was also a way of thinking, or learning, but a different kind of process than science or engineering. She believed that in science and engineering students could end up with one or two correct answers. On the other hand, when they learned math in school they always tried to find the one correct answer. She said, "Math is concrete, like you do step by step to help you solve an equation. There is almost always a right answer you try to get. Where in science each question can have more than one answer and that doesn't mean you are wrong."

As for technology, Reese believed it can be and should be integrated in science, math, and engineering. However, in order to construct a meaningful learning experience, teachers need to understand why they want to use technology in their teaching. In other words, what did they want their students to learn from integrating technology? She said, "Teachers have to really understand the technology and be really comfortable with it so that technology helps the learning and doesn't take away from the learning. Otherwise, it becomes more about the technology than the actual lesson." For example, Reese talked about her expectations related to technology in her STEM integration lessons. She believed that although she used technology as a tool in her STEM integration lesson, her students did need to understand the meaning of using technologies. She said, "Even though [students] are not creating [a genetically modified organism], [students] still need to understand what is a gene gun and how people use it," and "Using the Internet to do background research, they [students] need to figure out what's a good source and what is not a good source for finding actual scientific information versus opinions."

In addition to her requirement of integrating three STEM subjects for a STEM integration lesson, Reese also believed that a STEM integration lesson should show students a way to apply existing knowledge from STEM subjects to different situations. She said, "For me, STEM integration should be something that is in addition to the things that are already going on in a class, whether bringing in something completely new or thinking about things from different perspectives." She used her chemistry class as an example to explain her idea of STEM integration. She said, "Like in chemistry, yes, there is math, but it is not like 'STEM' math. It is just arithmetic you need to get through solving the problem that you need to be able to solve in chemistry." She did not consider students using math in a chemistry equation to solve a problem to be doing STEM integration. She said, "Particularly, math is in [chemistry] already. I don't think emphasizing the math in stoichiometry is STEM integration. I don't think that [using math in that way] really adds to the course." She believed a STEM integration lesson needed to have students actually thinking about the content knowledge that they had learned, taking time to reflect what they had learned from different STEM subjects, and applying that knowledge in a project. She said, "STEM integration is like a process. A process that I can use to teach my students how to apply what they have learned on a new and comprehensive level." Therefore she felt if she could not tie in what students had already learned then that was not STEM integration, even though it had integrated three STEM subjects. Reese believed that her Genetic Engineering project was a good example to demonstrate her view of STEM integration. She said,

> [The project] ties everything together, everything that we had talked about in the semester. Kids need to think about what scientific knowledge or information they have to use. The technology parts include a virtual lab and simulations, and other technologies, such as a gene gun that we have been talking about. Engineering comes at the end where [students] came up with their own project.

Pedagogies needed to achieve STEM integration. To Reese, the biggest focus of STEM integration was science content knowledge. She said, "Science probably is the biggest part of [my STEM integration focus], because I teach science." Her STEM integration lesson needed to address the new Nature of Science and Engineering standards. She explained, "So I still focus on, especially in chemistry and physical science, fulfilling the standards and using the textbook resources." She used her Genetic

Engineering project as an example and said, "[The project] has the science that addressed the standards. Kids who are taking this class have to have passed biology already. So we focus more on DNA, protein, and modifying DNA and protein." She did not want to only use science content from a textbook. Instead, Reese wanted her STEM integration lessons to bring in more "real-life science" information to her students, too. She said, "One of the focuses in my STEM integration lessons is how to make students really understand what scientists really do in their work. Just get kids to realize that scientists are people, too." She believed her students had misconceptions about how scientists do their work. She said,

> [Students] don't realize that scientists usually have a goal to what they are researching and are usually trying to solve problems. So I think whenever you can give students as close to an authentic experience of what a scientist really does, it helps them and they can actually get interested in it.

Besides showing students what real life science is, Reese also particularly focused on bringing ethical issues into her Genetic Engineering project. Ethics issues were another part she tried to tie to the standards. She wanted her students to understand that every decision they make has a consequence, especially in the biotechnology field. She said, "I focus a lot on the ethics and the outcomes. I want kids to think about, 'OK, if this [genetically modified organism] actually happened, how would that affect the environment or the people and the world?"

Reese also wanted her STEM integration lessons to be able to give each individual student opportunities to shine in his or her own way. She did not grade students' projects one versus another. She wanted to see how well students do with their abilities. She said, "[STEM integration] allows for some differentiated instructions where maybe the lower kids and higher kids can work to the best of their abilities. I don't necessarily think one is better than the others."

Learning outcomes for students when using STEM integration. Reese's STEM integration lessons also focused on how to get students to use what they had learned in a new way. She wanted her STEM integration lessons to actually help students apply their knowledge. Instead of compartmentalizing what they had learned in different subjects, she wanted her lessons to help her students see and use the knowledge as a whole in one project. She said,

> I want to focus my STEM activities on how to pull together ideas and things that [students] have learned in my class and other classes previously. So they actually apply and demonstrate what they have learned, not just recite or repeat what they have learned.

Reese believed that well done STEM integration could really bring a meaningful learning experience to students. She said, "If [STEM integration] is done effectively and in the right way, it brings a meaningful experience for kids. It gives them a chance to think about what they have learned in a new way." Therefore to Reese it was very important to have an overarching theme combining everything together. She believed that she did a good job of using STEM integration in her Genetic Engineering project. She elaborated,

> I feel in biotechnology I have done a very good job of having a theme for the class, which is genetic engineering. In that [Genetic Engineering] project students need to come up with their questions and use their knowledge in a new way.

Life skills. To Reese, STEM integration also taught her students a lifelong skill that was not in the textbook. She believed STEM integration helped her students think differently in terms of failure. She believed most of her students came to her class with a mentality that everything has a correct answer. She said,

> [Students] don't see the value if things don't work the way that they planned. I think this is one of the biggest downfalls of the kids. Kids come in thinking there is one right answer and if they don't get that right answer they are wrong. They don't realize that they can learn from the answer that they don't expect to get.

A STEM integration lesson helped her students understand that most real world problems did not have a right or wrong answer. Everything has its value in science, even if it is a wrong answer. She said, "[STEM integration] gave [students] the idea of trouble shooting and things didn't always worked the way they planned. That was what [students] needed to understand and to value."

Models of implementation of STEM integration. Reese believed that the Nature of Science and Engineering standards were a big push for her to use STEM integration. She explained, "The Minnesota Department of Education believes that STEM is important because they put it into the science standards. So I think it's going to be important that teachers try to integrate STEM as much as they can." Reese thought that integrating any STEM subject as a small activity into different units could not be considered using STEM integration. She said, "Like in my chemistry classes, I have used some technologies and mathematics in many little units, but I don't think those are STEM integration," and "I have integrated math and technology a little bit here and there in my chemistry class, but that is not STEM integration. I need a project to integrate everything." She was also convinced that using small STEM activities was not an effective way to do STEM integration. She said, "I think STEM integration is ineffective if you are just throwing it into one mini lesson. I think it is more effective if you can use it as a framework for the entire class," and "[STEM integration] is like a lesson plan, not just parts of it. You use [STEM integration] to frame your entire class."

Reese's view of STEM integration had an influence on how she wanted to integrate engineering. She believed the best way of using engineering was to use it as a glue to tie the other STEM subjects together. Reese considered engineering to be a process of finding a solution to a problem. She said, "Engineering obviously is coming up with a solution to a problem." Therefore she believed students had to possess a certain amount of content knowledge before she could use engineering in her teaching. She said, "Engineering is usually the last piece, after students acquire all the knowledge that they need. [Engineering] acts, something like, to get kids trying to recall things that they have already learned." On the other hand, Reese had completely different thoughts about integrating math into her STEM integration lessons. She believed if there was any math, it should be at the beginning of the STEM integration lessons. She said, "I think if there is math involved that would be introduced at the beginning when [students] are learning about the science that is required," and "[Math] is a tool. For example, in chemistry you need to solve an equation or we do graphing, so that is where the math comes in." In the big picture, Reese built students' prerequisite information, such as math and science content knowledge, at the beginning of her STEM integration lessons. Then, engineering came at the end and acted as a process to build a product or to solve a problem by using all the content knowledge. She was not particularly concerned if her STEM integration lesson had a technology piece. She said,

> I think at the beginning of the unit, it would be the background information, like the science and math content knowledge that they need to learn. In the middle, it would be some kind of experiential activities where they [students] can see what they have been learning about in action. In these activities, I may or may not use technology. Then, engineering would be at the end where they [students] would be trying to come up with a product or an answer to a question.

Reese also felt her STEM integration lesson was like an alternative test. It was like a very valuable assessment tool. STEM integration lessons not only helped her know what her students knew or did not know, but they also gave her great opportunities to fill her students' "unknown" gaps immediately. She explained this perspective by using her Genetic Engineering project. She said, "[Genetic Engineering project] is like an authentic assessment. Kids show what they actually know about this project. It is kind of an alternative to a test," and "I can really tell who is getting it and who needs more help. I can help kids with the things that they don't know straight away. If they take a test, I wouldn't necessarily have the opportunities to help."

Issues or difficulties in implementing STEM integration. Reese identified four difficulties that she had when she used STEM integration. First, she believed the nature of different subjects in science, such as chemistry and physical science, posed different issues in using STEM integration. Second, because students' abilities varied, she was concerned about the specificity of the project instructions that she should give to her students. Third, she considered herself to be a new teacher so she felt that she was still learning how to do STEM integration. Finally, she felt because she had at least 30 projects running at the same time, it was hard for her to spend time with each group and to remember what students' projects were.

How to implement STEM integration in different subjects. Reese taught both chemistry and biotechnology courses and felt that she had different difficulties when she tried to use STEM integration in each of these classes. She said, “I think in biotechnology it is hard to do math, and it is hard to add engineering into chemistry.” Although she had a hard time integrating math into her Genetic Engineering project, she felt it was a successful STEM integration lesson. The reason was that the Genetic Engineering project addressed the Nature of Science and Engineering standards. She said, “I think [the project] is a good STEM project, because I do try to bring in the engineering ideas. These are things in the standards that I need to follow.” Compared with her biotechnology class, Reese believed it was a lot harder for her to use STEM integration in her chemistry class. She said, “In chemistry, I don’t have a big overarching theme of STEM as I do in my biotechnology class. I cannot show my students how chemistry is used every day by actual chemists.” She also believed that the way chemistry was taught in school made it harder to use STEM integration. She said,

> [Chemistry] is so sequential. Like first we learn about matter, then we learn about atoms…So here we are, halfway through the year and we haven’t really even gotten to the reaction yet. If [students] don’t have the background information about what chemical engineering is, what a compound is, and what a polymer is, they are not going to be able to really understand the meaning of using STEM integration.

Students’ abilities. Although Reese had given a rubric to her students on the second day of the Genetic Engineering project, some of the students just could not follow the rubric very well. She said, “There are some kids that just completely miss parts of the rubric. I have to remind them or point out what they need to do for them.” She believed the rubric was very clear about what she expected her students to complete in the Genetic

Engineering project. However some students still asked for more specific instruction. For example, she said, "[Students] ask me how many slides they need for their presentation. So I said, 'If you need five, just do five. It's your decision, but I will not put a 100 on it though.'"

Also due to students' abilities, it was a big challenge for her that all the groups in one class did not work on their project at the same pace. She said, "They [students] are working on a different time line. It is hard for me to tell them, 'Hurry up, you are so behind.' Some kids just don't use their time wisely. Some kids just don't know what to do."

Reese wanted her students to complete the Genetic Engineering project by using their judgments. She did not want to give too specific instructions besides the rubric. She said, "In a real world setting, no one really tells you what to do. You just have to know what you need to do," and "[Students] need to use their knowledge and imagination to figure out what they want to do for this project.'" Therefore, it is hard for her to find the right moment to intervene. She said,

> I don't really know how to get the kids to think more critically without giving them ideas. For example, this year I have a couple people that want to make fast growing pineapples. I was like, 'OK, that is cool, but what does that really do to help people?' [Students] said, 'Because people like pineapples, so we want them to grow faster.' Well, it is a reason and I cannot say, 'That is a bad idea', right?

Doubts. During the interview, Reese expressed that she was a new teacher, both in using STEM integration and in her teaching career, several times. She felt it was hard for her to do STEM integration in a way that she wanted. She said, "I think the biggest thing for me is just learning how to integrate STEM effectively in the way that I would like to." Therefore she felt the safest way to teach STEM integration was to follow the standards. She said, "It is not integrated in the textbook. I am a rather new teacher. So, a lot of my framework in my classes is from the standards and from the textbook." She felt she would spend a lot of time on a project. Therefore if the project did not tie multiple things from the standards together, she did not feel it was worth her time to do. She said,

> I haven't been teaching long enough to have come across to a lot of different activities and things. If we found a textbook that has lot of STEM stuff, I think that would make it a lot easier. I would like to do [STEM integration] better. I am just not exactly sure how. Sometimes I feel I am not quite ready to use STEM integration at the level that I want it to be.

Large class size and too many class sessions. Reese had a goal when she did her Genetic Engineering project. She wanted to spend time with each group talking about their project. She wanted to make sure all of her students ended up with a certain understanding of the project. However it was hard for her to do that with more than 30 projects running at the same time. She felt she did not have enough time to give to her students. She said, "I probably had 30 different groups who had 30 different projects this semester. I try to spend time with each group, but it was hard," and "For some groups that know what they are doing, I still want to make sure that they are doing OK. But, with some groups, I need to sit down and spend a lot of time with." She had an idea that might solve this problem. She said,

> I have toyed with the idea of having the kids set up an appointment with me, like I can sit down with each group for 10 minutes, like, for this 10 minutes I am yours. I am not going to go help anybody else. [Students] will need to be ready with their questions and have an outline for the things that they want me to help them with.

Other. Reese believed STEM integration made her students really think outside of the box. Her students became more sensitive about what happened in the world. She said, “When the oil spill was really big last year, kids were trying to solve that problem. They did really try to come up with solutions to the problems that are affecting people around them.” She thought it was very interesting to listen to students express their ideas in their Genetic Engineering project. She said, “I like hearing [students’] ideas. The kids come up with some really creative ideas and problems, and how they are going to try to solve that problem by using genetic modification.”

She also believed that her students needed to practice their public speaking skills. They needed to know how to conduct a concise presentation within a given time. Therefore, she made students do a presentation as part of the final product for her Genetic Engineering project. She said, “Presentation skills are public speaking skills. Kids can never practice those enough. They have to interact with people and discuss their ideas. They need to learn how to talk concisely.”

Sid

As a teacher, Sid believes his job is more that of a mentor/guide as opposed to a person who delivers science content all the time. He wants to be a teacher who helps influence young people to be confident in their abilities and know they can change their outcomes through efforts and problem solving. He does not believe memorization is a way to learn science. He believes teaching science requires students to think because students must learn to process information.

Structure of the STEM Integration Class (Egg Drop project)

This section describes the implementation of the Egg Drop project, which is a STEM integration unit taught by Sid. The Egg Drop project was implemented in a ninth-grade physical science class in School D. It was a 3-day project, and each class was 50 minutes. There were 32 students in the class. The project was observed at the end of March 2011. Sid's goals for the unit were that students should be able to use both scientific content and the engineering design process to build an egg protection device that can keep an egg from breaking when dropped from at least 2 meters. The following are detailed descriptions for each day of the Egg Drop project.

Day 1. Sid started the class by spending about 15 minutes reviewing the students' tests from a previous day. Then he reviewed the concept of momentum with students. After that, Sid introduced the Egg Drop project. He asked students to take out their Egg Drop project worksheet (Appendix F) and said, "Let's look at the objective. First, the standard is that you need to build something that can survive 2 meters. It is like slightly taller than me." He set up an expectation that every group should have built an egg device that would survive a 2-meter drop. He asked students how hard it was to break a hardboiled egg. One student replied, "It is just as easy as when you try to break a regular egg." Sid said, "Yes. So, you cannot have a crack on your egg when you drop it from 2 meters. This is crucial. You have to think about what you need to do." He told the class that it was a very reasonable expectation because he rarely had students whose eggs could not survive this height in the past. He said, "If you cannot survive this height, you have to ask yourself how much effort you put into your project." Then he started to talk about the rules. First, the egg protection device could not have a parachute. He explained this rule to students, “The idea behind no parachute was to figure out a way to prevent collisions with materials.” He asked students, “How is that an analogy to a car crash by not using parachute?” A student said, “If you use a parachute, you can slow the egg down, but cars do not have a parachute.” Sid said, “The idea is that we are trying to change impulse. We are trying to make force stand for a long period of time so that it gets smaller. We also still need to change the momentum in the same way.” Second, students could only use the materials that Sid provided to them. If they went over the budget, Sid would take 5 points off of their project.

Sid then told the class that their eggs needed to be inside the egg device that they built. He said, “I’ve had groups ask, ‘Can I build a device around an egg?’ Yes. Your egg can be removed from the device, but when you do your drop test, your egg needs to be inside your device.” He told students that the purpose of this project was to keep an egg from breaking. A student asked, “Can you drop an egg on something?” Sid replied, “No. The device has to be symbolized as a vehicle. You are going to put an egg into something and that something you are going to drop.”

Then Sid moved on to talk about test drops. Each group would get a chance to do an egg drop test for free. After the free drop, students needed to buy a hardboiled egg from Sid. Students could drop the hardboiled egg that they bought as many times as they wanted until they were satisfied with their test. A student asked, “If the egg breaks the first time when you drop it, what are you going to do?” Sid replied, “That is why you need to think. Think how to build a device to protect your egg. This is something that you really need to think about." Then, he gave a successful example to his students. He said, "Usually, students who build the best three devices are the last three that buy the materials…do you know why?" Students answered, "They think a lot about how to build the device." Sid said, "Yes. That is what you need to do. The groups that think the most, the hardest, generally do better. You have to plan ahead and that is what you need to work on." Then Sid pointed out that students needed to fill out the materials table and to have some strategies on how they are going to build their device by talking to their partners. He told students that these were the processes to help them think and plan what they wanted to do. He said, "Planning the egg drop device should take 3 times longer than actually building it. Does that make sense to you?" He once again told students that they needed to work on planning, and then they would start to build and test their device the next day. He reminded students that the final test would be on Friday and that would be the test that students would be graded on. After he explained everything, he let students get into their groups to work on the project. Sid walked around helping students and answering their questions.

Day 2. Sid started the class by asking if students had any problem filling out their materials table. He told students that they needed to hand in their budget sheet before they could do their egg drop test. He wanted them to take a look at the materials that he set up at the back of the classroom and said, "Everything you need is at the back. You can go get your own stuff, but please try to keep it as clean as possible." He reminded students that they should try to build the cheapest device that could survive 2 or more meters. After he gave brief instructions, he let students get into their groups and work on their device. Most of the students had their prototype on their worksheet already and had actually started to build their devices. Sid was busy checking students' worksheets and gave eggs to them. The students did not really have problems figuring out their budget. Sid reminded the students that when doing a test drop, even a little crack meant they would not pass the test. He said, "If you don't want to buy an egg from me, you should use your free test wisely. You should really try to build a device that could survive 2 meters." Some students started to do their test drop. A group dropped their device, checked their egg and discovered a crack. The group told Sid what happened and he said, "Now, go back to thinking more, like where can you change your design."

Day 3. Sid started day 3 by checking the students' progress. He said, "Has anyone not done the first test yet? I hope not. By now you should have tested your device at least once already." He wanted students to consider if they needed to modify or change their device before the final test. He said, "You will have about 20 minutes to change your design. After that, we are going to do the final drop and that is what you are going to be graded on." He wanted students not to worry about the questions on the worksheet yet because they would have to answer the questions after their final drop.

During the final drop, students had to drop their device from a balcony. One student from each group dropped the device and another one picked up the device and checked if the egg was intact. Students could also earn extra points by dropping their device from 6 or 8 meters, as long as their device survived from the 2-meter mark. After students finished their test, Sid asked them to go back to the classroom and finish their worksheet. In the class he said, "I want you to talk to your partners about what you did to protect your egg. Did it work? Also, take a look at other devices, especially the winner, and think about why that could survive from 8 meters." He also reminded the students to finish their worksheet and think about what changes they would make if they had the chance to design their device again. He ended the class by saying, "I hope you have a better idea about collision and momentum. This is what this project is all about. Now you should have a better idea of how to answer the questions on the worksheet." After that, he asked students to hand in their worksheet before they left the class.

Interview Results

Sid's view of STEM integration. Sid believed that science, technology, engineering, and math were all heavily integrated and that it was natural to combine STEM subjects together. However, each subject might play a different role in a STEM integration lesson. Sid stated in STEM integration that science was the knowledge behind it; engineering was the process of doing it; math was the tool to give the quantity to it; and technology was what comes out of it. He said, "To me, totally integrating STEM is making it systemic." Sid believed that STEM integration could not be separate from problem solving and each STEM subject played a very important but different role, such as a tool, a process, or an outcome for problem solving. For example, he expressed his view of what science is by saying, "I like to approach science as being a method of solving problems. I want the primary focus to be on solving problems or finding ways to solve problems." For math, he said, "Math is a language that is used to express quantity that you can measure. We make [students] use [math] to express some answers. So it ties into that whole problem solving process," and, "The nature of math in science means application of concepts. An idea to show them [a solution for a problem] works. It is a tool." For engineering, he said, "Engineering is the process of applying science to an idea and applying the math of scientific inquiry into creation and innovation. It is a process of problem solving." As for technology, he said, "Technology to me is basically any usefulness. How can we make our life better? Any time that we use science to make life better for us is technology. Engineering is the process and technology is the result." Therefore, Sid said, "It is like science is advanced by technology. You can't have technology without engineering. You can't do science without knowing a lot of math. You have to kind of just squish them all in." Because his view of STEM integration needed to integrate all STEM subjects, Sid critiqued his Egg Drop project. He felt that it was not a complete STEM integration lesson. He noted that the Egg Drop project was not his ideal STEM integration lesson because it did not have the aspect of mathematics in it. He said,

> I don't think [the Egg Drop project] is fully integrated enough to be my ideal of a STEM activity. I guess my ideal one should include all aspects [of STEM subjects]. It lacks the aspect of math. It is not what I would think of as a perfect STEM integration lesson.

Sid also believed that STEM integration was a very powerful robust tool for teaching students how to apply the knowledge that they had learned from different STEM projects to solve a problem. If a STEM integration lesson was fully integrated, Sid believed that students should be able to use all the knowledge that they had learned to come up with lots of different ideas to solve a problem. He said,

> I think the power comes from designing a STEM integration that would come from finding ways to push those [STEM] subjects back together. So, we learn math and science. We learn the process. We learn how to use this

> tool, technology. Now we have a problem. Do the math, do the engineering, use the technology and apply the science to solve this problem.

Sid used a different STEM integration lesson, the Chemical Reaction Submarine, to better represent his view of STEM integration. He said,

> [The Chemical Reaction Submarine] was the whole unit. It was not just an activity. We looked at different chemical reactions. For example, we looked at how to use the endothermic and exothermic properties to create a heat pack. After that, we applied the knowledge that we had learned about different chemical reactions to our submarine project. It had all the aspects of STEM subjects.

Pedagogies needed to achieve STEM integration. Sid believed there were two main foci of his STEM integration lesson, and these ideas could not be separated from each other. The two foci were as follows. First, Sid believed a STEM integration lesson needed to provide his students with more opportunities to engage in problem solving. Second, he wanted his STEM integration lessons to help his students connect and apply what they had learned in different STEM subjects to a new situation. He said, “To me, STEM integration is finding ways to give more opportunities to students to solve actual problems in my class, and you have to fully integrate all content into one.” Therefore, in his STEM integration lesson, a hands-on activity that had a problem that needed to be solved was a vital component. He valued the “trying” phase, such as testing different materials or solutions to find out the best answer, in a STEM integration project. He said, “It is the idea of manipulating a project so [students] actually have to physically try it. That makes them learn.” He believed that “trying it” was a very important component in learning. Students should solve a problem by using their own ideas. He focused his STEM integration lessons on the activities that could help students generate their own ideas or solutions and enrich their learning experience. He stated that was the way a teacher should teach his or her students. He said,

> Now is more like, let's tinker with it. Let's play with it. Let's get it to work. This is a 'We wouldn't know until we try it.' Instead of me giving [students] directions 'Do this and do that', this is how they should learn and how we should teach.

Sid believed that a STEM integration lesson could provide more learning opportunities for students who had different learning styles and also could make learning more interesting to students. He said, "I think [STEM integration] gave more opportunities for everyone to get one good shot at what they are good at," and "STEM provides a variety of ways to engage [students] to learn, not only one way, but multiple ways to engage different learning styles. It makes [learning] more interesting." He believed the more students struggled and tried on their own ideas to solve a problem, the more learning would occur. He said, "I don't really think they [students] get what science is until they are wrong for a long time. We learn better from being wrong." He explained this by saying, "I think kids need to tinker. I think they need to touch things, play with things, and realize they just have to explore the answer by trying their ideas or experiments with different materials."

Learning outcomes for students when using STEM integration. Sid wanted his STEM integration lesson to engage his students in learning science. Based on his teaching experience, Sid stated that STEM integration lessons made science content that he needed to teach more interesting to students than in a regular science lesson. Another goal for Sid's STEM integration lessons was to show his students the essence of science.

He wanted students to employ scientific thinking all the time when it came to the questions that they needed to solve. He said,

> I think just overall, [a STEM integration lesson] is a better way to introduce inquiry and to show [students] that the philosophy of science is all about solving. It is about thinking. It is about having your own ideas rather than just regurgitate what you have been taught.

Sid believed when students used their independent thinking skills it was very easy for him to see where students did not understand or where they had misconceptions about the concepts he taught. He felt it was easier to find out students' misconceptions in a STEM integration lesson than in a traditional lecture type of lesson. He said, "I think I see more students' ideas through STEM than anything else I do. That is why I am able to find out misconceptions and correct them." Therefore, one of Sid's goals was to help his students to become independent thinkers when they do problem solving in his STEM integration lessons. He said, "If students want to get engaged [in a STEM integration lesson], they can figure out a lot of ideas and do a lot of interesting thinking. I think that is a huge benefit to them."

Sid also was convinced that when students do a STEM integration lesson they have a better opportunity to understand that most of the answers to real-world problems do not have a right or wrong answer, rather a good or bad answer. Sid wanted his students to understand that there were no wrong answers. Sid said, "It is that systematic integration of 'Now, what does this mean?' in different situations that makes students realize an answer for a problem isn't always 'yes' or 'no'. [Students] should say good or bad instead of right or wrong."

Life skills. Sid believed students solving a problem by using their own ideas is one of the life skills that students need to master. He considered that to be what students needed to become successful in their life. He said, "I think using your own ideas to solve a problem is a type of thinking that students have to have to be successful individuals. Any time you can think independently about a problem, I think that enriches your learning." When Sid did his STEM integration lessons his students were willing to try any idea that came to their minds. He said, "I think it is less pressure for [students] to be wrong when they are doing these [STEM integration projects]. Because if you were wrong, you just keep going and try again." He believed that perseverance in a STEM integration lesson helped students to realize some lifelong lessons. He said, "I don't care if [students] don't remember what velocity is after 1 semester. I want them to know it is all right to have an answer that was not what they expected," and "I want [students] to try. It is the process that helps you learn. Those are the things that they need to understand, even after they leave school."

Models of implementation of STEM integration. Sid had a very flexible perception about how to use STEM integration. If he could, he wanted to use STEM integration as a whole that integrated all the STEM subjects together. He said, "I think ideally I would like to see STEM integrated across everything." For example, Sid wanted to treat his STEM integration lesson as a lesson plan itself, not just as parts of any of his lesson plans. He said, "Doing STEM integration is not like you stop what you are teaching and do STEM. [STEM integration] has to be flowed into [a unit]. It is not just parts of a lesson plan. It *is* a lesson plan." He considered that the goal of using STEM integration was not about asking students to complete a project, but rather to help them become independent thinkers. “I would like [a student] to know this rather than regurgitate it. You have to start coming up with your own ideas about what this is, about how this works. That’s what makes you more successful in the long run.” He wanted his students to be able to use their problem solving skills anytime and anywhere. Sid said, “I like to have [students] think about what is going on in the real world. If you can’t ever do this as an independent thinker you are going to be at a disadvantage to those who can.”

Although he wanted to use STEM integration as many times as possible in his teaching, he found that there were some days that he just could not use STEM integration in his lesson plans. He said, “[STEM integration] is like inquiry. You can’t do this every day. You do have to eventually tell [students] the answers. You can’t just make them guess. They need to know things for their standardized tests.” Also, although Sid believed a fully STEM integration lesson should have all the STEM subjects in it, sometimes STEM integration lessons just could not have all the subjects. He felt that he needed to be very flexible in applying STEM integration. He said, “I want to integrate, but it doesn’t have to be like the whole piece of it. To me, it could be all or it could be some.” Sometimes he used his STEM integration lessons as an introduction to the next lesson that he would teach or as a culminating project to engage his students in learning science. For example, the Egg Drop project served as an introduction to the transition from his momentum lesson to the energy unit. The Egg Drop project was an advance project used to prepare students for new scientific content that they would learn in the next lesson. On the other hand, sometimes he used his STEM integration lesson as a final project that students needed to complete at the end of a unit. For example, in the Chemical Reaction Submarine project, students needed to use everything they had learned from that unit to complete the project.

However, no matter how Sid used his STEM integration lessons, he was very certain that students needed to at least have some content knowledge to be able to do STEM integration. He said, “[Students] need to have something concrete to attach a concept to. I think that is where the integration comes in.”

He also considered STEM integration as a way for every student to shine in their own way. He wanted to design his STEM integration lessons as a way for every one of his students to learn something. He said,

> When I think about STEM integration, I think everybody had a good shot to get some ideas out. Many students are great students. They do very well on pencil and paper test, but they are terrible independent thinkers. On the other hand, some students don’t do tests very well, but they can come up with the most amazing idea that I have never seen.

Sid used a specific student as an example to further explain this idea. He had a student who did not typically do well on his tests. One day after a STEM integration project, he came to Sid and talked about the differences between some cars. Sid said, “You know, with a little bit of engagement, he learned something that day. I saw some lights come on for him and I thought that was great.”

Issues or difficulties in implementing STEM integration. Sid expressed three concerns or struggles in planning and implementing STEM integration. First, he believed students needed to be motivated in order to learn anything from a STEM integration lesson. He did not know how to motivate the students who did not want to be engaged. In addition, he was aware that STEM integration was fun for students and that they might not take a STEM integration project seriously. Second, he had a hard time assessing students' learning in a STEM integration lesson. Third, he felt the availability of materials and the amount of time he had were important factors that influenced how he designed his STEM integration lessons. Sometimes because of lack of time and materials, he could not do something that he wanted.

Students' motivation. Sid believed STEM integration was for students who wanted to participate. He said, "For me, STEM is not a magic cure for those who simply don't want to participate. STEM is for those who want to participate and are pretty good students." He stated that students' motivation was one of the biggest factors that influenced if he wanted to use a STEM integration project by saying, "I think that motivation is the biggest battle when I do STEM activities. What do you do to the students who just don't want to participate?" He felt if his students did not engage in a project, then what was the purpose of doing a STEM integration project. Sid believed some of his students had abilities to do a STEM integration project, but they just chose not to try. He said, "The quality of the product is very poor. You can tell it is not from their lack of understanding or knowledge. It is from the lack of motivation." Therefore, Sid emphasized the importance of motivation by saying, "It is that whole motivation to come up with a good product, a good performance. I don't think it was because of their abilities. I think it is just because you are just not motivated." Sid believed engagement to be more important than a student's ability to do a STEM integration lesson. He felt that students' abilities could not supersede engagement. He said, "I find students' abilities usually don’t matter. Even students who are struggling with their abilities—if they are engaged they usually have great results and good products.”

Although he asserted that students’ motivations were not really equal to students’ abilities to do STEM integration lessons, he also made a conclusion based on his experience. He stated, “Students who had motivation to do a STEM project usually were those good students. Students who lack motivation to do a STEM project usually were the students who had troubles in learning science.” Therefore, he believed STEM integration lessons were for students who were at the top 60% of the class. He said,

> [A STEM integration project] is actually an enrichment of ‘OK you are already smart, let’s make you smarter. Let’s make you even more talented.’ I think STEM helps move everybody up. But when you talk about participation, assessment, and getting smarter in my class, I think it cuts off a little bit more than the middle, because the one who is at the very bottom sees it [doing a STEM project] as a chance to take a break.

About assessment. Sid expressed a concern that he had a difficult time assessing his STEM integration lessons. He felt a STEM integration lesson could not distinguish if a student is lacking motivation or does not understand the project. One of the learning goals for his STEM integration lessons was to generate students’ independent thinking. He felt he could not put a very fair judgment on students’ ideas or solutions when they tried to solve a problem. He said, “How do you assess fairly? Obviously there is going to be a wide range of answers. Do you assess on right and wrong? Even if they are wrong, that’s a lot of ideas.” In addition to that, he could not assess students’ motivation level, either. He said, “The weakness is that [a STEM integration lesson] relies heavily on intrinsic motivation, and it can be very difficult to assess. You see kids sitting there not helping, not learning, and that makes it difficult.”

Sid felt that in a STEM integration lesson he could not really assess students' learning. For example, in his STEM integration lesson, there was no test that students needed to take to show how much they had learned. Therefore, some of the students saw doing STEM integration as the time that they did not need to be very serious about their learning. He said, "When you do a project like [a STEM integration project], you have to hold a high standard, otherwise every time you do it, it will be just like 'oh we have goof off time,'" and "Some students see this as a chance that they are not going to get graded on. They feel that they just don't have to participate in it."

Time, materials, and large class size. Sid felt that his Egg Drop project was not a fully integrated STEM lesson. During the interview, he provided several ideas to change his Egg Drop project to become fully integrated. For example, students could drop their devices on a force plate so they could collect data to do more calculations with the acceleration besides just filling their budget sheets. However that also meant Sid needed more time to implement his Egg Drop project. He said, "Time is a huge factor. I mean we only have 3 days. I definitely can add more math pieces in there, but that also requires more time to do the project," and "Can we use the motion detectors in [the Egg Drop project]? Absolutely! But kids struggle with the math. It is like we really need all of those 3 days to build, then drop. Time is probably the biggest issue."

In addition to that, Sid was also concerned about the materials he could find and use for his STEM integration lessons. Sid had decided not to do the Egg Drop project again, but instead a Cardboard Chair project with his students. However he could not find a place in his classroom to store all the cardboard that he needed for the Cardboard Chair

STEM project. He also could not find enough cardboard for his students to use. Therefore, instead of doing the chair project, he changed his plan to the Egg Drop project. He said, “I was actually going to do something different; building cardboard chairs. I just couldn’t do it. If I am going to do that, I will need a garage to store all the cardboard,” and “Materials are always an issue. I need materials that are easy to access and fit well.”

There were 32 students in his class and Sid felt it was too many students. He could not give each student the attention that they needed. He also needed to shout when he had an announcement to make because when students were doing their project, they were talking, too. In fact, Sid lost his voice during the second day of his Egg Drop project.

Other. Sid believed that high school was like a giant smorgasbord. Students in high school needed to find or develop their career interests. In order to do that, they needed to try everything. He believed a high school should provide students opportunities to try everything. Therefore he liked doing STEM integration lessons because it gave his students all the flavors of the different STEM subjects. He said, “The [STEM integration] lesson gives [students] that kind of exposure, that kind of buffet line, just try something. If you like doing the little tinkering projects in science, then you probably would like to be an engineer.”

Summary of Chapter 4

Chapter 4 presented the five teacher cases for this study. This section l provided a brief summary of each case. Kathy’s STEM integration lesson, the Robotics unit, was about one and a half months. She did not design her Robotics unit. She taught her

Robotics unit in a way that her school wanted her to teach. In her Robotic unit, engineering design was one of the major concepts that she wanted her students to learn and practice. Her view of STEM integration could not be separated from problem solving. She believed that the pedagogies needed to achieve STEM integration should be focused on problem solving skills or problem solving processes. She believed that problem solving was where inquiry and engineering design overlapped in a STEM integration lesson. To Kathy, integrating mathematics and technology was an afterthought. When she designed her STEM integration lesson she first wanted to integrate science and engineering and then mathematics and technology. She also believed that it was very important to follow the Nature of Science and Engineering standards when she designed or taught STEM integration lessons. Kathy used an engineering open-ended problem to guide her Robotics lesson. She understood that a STEM project did not have to have a hands-on final project, but she preferred to have one in her STEM integration lessons. The desired learning outcome for her STEM integration lessons were that she wanted her students to become independent thinkers by using their own thinking to solve a problem, and to apply their existing STEM knowledge. Kathy believed when her students practiced the engineering design process, her students learned to deal with their frustration by trying different solutions to solve a problem. Kathy held a perception that students should at least have learned some certain STEM knowledge before they can really understand the meaning of a STEM integration project. Therefore, Kathy stated that ideally the best time to do STEM integration was at the end of each unit. However, her Robotics unit was opposite from her perceptions. This was due to her Robotics unit was school-orientated.

Kathy expressed five concerns after she implemented STEM integration lessons. First, if a teacher does not have necessary technology, Kathy believed that can block design and implementation of STEM integration lessons. Second, because she wanted her students to apply their STEM knowledge in her STEM integration lessons, she believed that her students' STEM abilities had great influence on how she could design her STEM integration lessons. Third, she considered herself to be a novice teacher who is still learning how to design and implement STEM integration lessons. Kathy was not sure the way that she implemented her STEM integration lessons was the good way to do STEM integration. Fourth, she believed that too many class sessions could reduce the quality of a STEM integration lesson. Finally, Kathy had hard time balancing the fun and learning parts in her STEM integration lessons.

Lisa taught the Genetic Engineering activity as her STEM integration lesson. It was a 2-day activity, and it was implemented at the end of her gene unit. Her view of STEM integration was highly related to problem solving. She considered STEM integration to be a process that could help her students to apply their existing STEM knowledge. Lisa believed that she needed to follow the Nature of Science and Engineering standards to design her STEM integration lessons. In addition to addressing the Nature of Science and Engineering standards, science content was another pedagogy needed in Lisa' STEM integration lessons. Lisa did not worry about integrating mathematics and technology in her STEM integration lessons. Lisa believed that problem solving, independent thinking, and creativity and imagination were the three unique characteristics in STEM integration. Lisa had three learning goals in her Genetic

Engineering activity. First, she wanted to use her STEM integration lessons to help her students becoming independent thinkers. Second, she wanted her STEM integration lessons to provide opportunities for her students to apply their STEM knowledge. Third, Lisa also wanted her students to pay attention to ethics issues in her Genetic Engineering activity. By trying different solutions to solve a problem, Lisa believed the nature of a STEM integration lesson helped her students learn to deal with their frustrations. When Lisa designed her STEM integration lessons, she always wanted the lessons to fit with the science topic that she wanted to teach. Lisa intentionally used the Genetic Engineering activity to help her students apply what they had learned in her gene unit. She also believed her genetic engineering activity addressed the Nature of Science and Engineering standards very well. Lisa stated four concerns after she implemented her Genetic Engineering activity. First, it was hard for a life science teacher to do some parts of engineering design process, such as testing phase. Second, she believed that her students might still need a lot of direction when they do a STEM project. Therefore, she was struggling to decide how much directions she needed to give to her students. Third, she believed that her students' STEM abilities had possible influence on how she designed her STEM integration lessons. Finally, she believed when she taught a STEM integration lesson she needed more time to implement it rather than a traditional science lesson.

Carolyn implemented the Candy Bag activity as her STEM integration lesson. It was a 5-day lesson plan. She taught the Candy Bag activity at the beginning of a semester. She wanted her students to be familiar with the engineering design process by doing the

Candy Bag activity. Carolyn believed anytime when she integrated any two of STEM disciplines, she was using STEM integration in her classroom. Integrating science and engineering was the key in her STEM integration lessons. Carolyn considered integrating mathematics and technology as additional pieces in her STEM integration lessons. She believed her STEM integration lessons needed to address the Nature of Science and Engineering standards. Therefore, she considered the engineering design process as a must in her STEM integration lessons. Carolyn wanted her STEM integration lessons to help her students engage in learning science. In her STEM integration lessons, Carolyn also wanted her students to apply their STEM knowledge. To understand scientific concepts and the engineering design process were the two major learning goals for her STEM integration lessons. She also wanted her students to understand the difference between a scientist and an engineer. Carolyn believed that the redesign part in the engineering design process helped her students understand the importance of endurance and persistence when they tried to solve a problem. When Carolyn designed her STEM integration lessons, she always put her students' STEM abilities and her desired learning goals for her students into account. She wanted to use her STEM integration lessons to help her students connect their existing STEM knowledge. Carolyn stated four issues after she implemented STEM integration lessons. First, she believed she needed to help her students step by step to complete a STEM project. She needed to give her students a lot of direction in order for her students to complete a STEM integration project. Second, she felt that she always needed more time to implement a STEM integration lesson than what she had. She believed if she had more time, she could do a better job in implementing a STEM integration lesson. Third, she did not know how to balance the fun part and the learning part in her STEM integration lessons. Fourth, she felt that it was hard for her to integrate mathematics in her STEM integration lessons.

Reese's STEM integration lesson, the Genetic Engineering project, was a 7-day lesson plan. She implemented the Genetic Engineering project at the end of her biotechnology class. She wanted her STEM integration lessons to help students apply what they have learned from her biotechnology class. Reese believed that STEM integration has to integrate at least three STEM disciplines. She believed science and engineering were the most important disciplines to integrate in her STEM integration lessons. Her STEM integration lessons aimed to help her students apply their existing STEM knowledge. She considered mathematics and technology as tools that she could use to help solve a science or engineering problem in a STEM integration lesson. Reese was convinced that her STEM integration lessons needed to address the Nature of Science and Engineering standards. In addition to addressing the standards she also wanted to provide her students with an authentic learning experience that simulated how a real world scientist or engineer would do their jobs. Therefore a real world open-ended problem played a very important role in her STEM integration lessons. There were two learning goals for her Genetic Engineering project. First, Reese wanted her students to apply their STEM knowledge, particularly science content knowledge, in her Genetic Engineering project. Second, in her biotechnology course, she believed it was very important for students to deal with ethics issues. Reese believed a STEM integration lesson helped her students think differently in terms of failure. Reese believed that adding a small activity to a unit could not be considered STEM integration. She believed a STEM integration lesson needed an overarching goal to connect different STEM disciplines. She believed engineering was the glue that tied the other STEM subjects together. She also considered STEM integration to be a very valuable tool for assessing her students' understanding of science content. Reese had four concerns after she implemented her STEM integration lessons. She believed that in different subjects a teacher could encounter different difficulties in designing and implementing a STEM integration lesson. Second, she believed her students' STEM abilities had influenced how she designed her STEM integration lessons. Third, she considered herself to be a novice teacher who has very limited experience in designing and implementing STEM integration lessons. Therefore she always had doubts about herself when she designed and implemented her STEM integration lessons. Finally, she believed that too many class sessions could affect the quality of a STEM integration lesson.

Sid taught the Egg Drop project as his STEM integration lesson. The Egg Drop project was a 3-day lesson plan. He used his Egg Drop project as a bridge to connect one science concept to another. Sid believed that a good STEM integration lesson needed to integrate all of the STEM disciplines, and that each STEM discipline had a different role. He believed that STEM integration could not be separated from problem solving. He stated that STEM integration was a process of problem solving that could help students apply the knowledge that they had learned. Therefore he wanted his STEM integration lessons to provide more opportunities to engage his students with problem-solving and to help his students apply what they had learned. He considered a hands-on activity that had a problem that needed to be solved to be a vital component in his STEM integration lesson. Sid valued the quality of independent thinking. He wanted his students to use their independent thinking skills to solve a problem and saw that as a major learning outcome in his STEM integration lessons. Sid believed a STEM integration lesson helped his students think differently in terms of failure. When Sid designed his STEM integration lessons, problem solving was always a “have to” component. He felt that his students needed to physically create a final product as part of problem solving in his STEM integration lessons. Sid also compared inquiry with problem solving. He believed that inquiry and problem solving shared a lot of common knowledge. Sid expressed three concerns after he implemented his Egg Drop project. First, he believed that students’ motivation was a key to doing successful STEM integration. Second, he was convinced that it was hard to assess students’ learning in STEM integration lessons. Third, he believed that limited time and resources were two struggles when he tries to design and implement his STEM integration lessons.

The data from the cases was presented in terms of the categories that emerged from the data collected for this study. Although all the participants have the same categories, the patterns in each category may vary. Table 11 provides useful information for readers to see some major patterns that emerged from the five participants in the seven categories. Table 11 also is a useful tool that helps the researcher to analyze the different and similar patterns in the seven categories from all the participants in order to construct themes. Nine themes emerged after analyzing the different and similar patterns in the seven categories from all the participants. The themes of cross-case analysis will be present in Chapter 5.

Table 11

Major Patterns that Are Emerged from the Five Participants in the Seven Categories

Categories	Participants	Patterns
View of STEM integration	Kathy	1. STEM subjects are highly related, especially science (inquiry) and engineering (engineering design).
		2. Placing science as the foundation of her STEM integration lesson, and using engineering as the glue to tie science and math concepts together.
		3. STEM integration cannot be separated from problem solving.
		4. School orientated.
		5. Engineering is the engineering design process. Technology is computers.
	Lisa	1. STEM integration is about problem solving. Students should use their STEM knowledge to generate their own idea to solve a problem.
		2. Independent thinking, imagination, and creativity are the key elements in STEM integration.
		3. STEM integration is a process or a thought that helps students to think independently like a real scientist.
	Carolyn	1. STEM integration is whenever more than one of the STEM disciplines is used together.
		2. STEM integration is a strategy to engage students to learn science and to make learning more personal to students.
		3. Integrating science and engineering is needed in a STEM integration lesson. Integrating mathematics is where measurements and calculations come into a STEM integration lesson.
		4. Mathematics and technology are afterthoughts in a STEM integration lesson. *(cont.)*

(Table 11, cont.)

Categories	Participants	Patterns
	Reese	1. A STEM integration lesson has to have at least three STEM subjects. 2. Integrating science and engineering is important in STEM integration. Science and engineering are highly related to each other. 3. STEM integration should help students apply existing knowledge by using an overarching open-ended question. 4. Engineering equals STEM knowledge. A teacher needs to be cautious when integrating technology because it may take away what students really need to learn. 5. Mathematics and technology are tools to help solve a science or engineering problem in a STEM integration lesson.
	Sid	1. STEM subjects are highly related. However, each subject may play a different role in a STEM integration lesson. 2. STEM integration cannot be separated from problem solving. STEM integration is a process of problem solving that can help students to apply the knowledge that they had learned. 3. Total integration is to integrate all the STEM disciplines.
Pedagogies needed to achieve STEM integration	Kathy	1. Problem solving is a key to help students become problem solvers. 2. Focusing on problem solving skills or problem solving processes rather than on content knowledge (such as when integrating mathematics actually focuses on the problem solving in science). 3. STEM integration needs to follow the Nature of Science and Engineering standards. 4. A real world open-ended problem is essential for STEM integration.
	Lisa	1. STEM integration needs to follow the Nature of Science and Engineering standards. 2. Science content knowledge is the major focus in a STEM integration lesson. 3. Engineering is engineering design. Mathematics is important in STEM integration but sometimes there is no room to integrate mathematics in life science. 4. A teacher needs to be cautious when integrating computers (technology), because it may take over students' creativity and imagination.

(cont.)

Categories	Participants	Patterns
(Table 11, cont.)	Carolyn	1. It is important to integrate science and engineering, but math and technology are additional pieces in a STEM integration lesson.
		2. STEM integration needs to follow the Nature of Science and Engineering standards.
		3. Integrating engineering design is important because it can help students apply scientific concepts. STEM integration also engages students in learning science.
		4. Mathematics and technology are tools to help solve a problem in science or engineering.
	Reese	1. Science content knowledge is the most important element in a STEM integration lesson.
		2. STEM integration needs to follow the Nature of Science and Engineering standards.
		3. An open-ended problem that simulates what a real world scientist or engineer does for his/her job is essential in a STEM integration lesson.
		4. Providing opportunities for a student to shine in his or her own way in a STEM integration lesson.
	Sid	1. STEM integration lesson needs to provide his students with more opportunities to engage in problem solving and help students connect and apply what they had learned to different situations.
		2. A hands-on activity that has a problem that needs to be solved is a vital component in a STEM integration lesson.
		3. STEM integration needs to provide students a learning environment where they can generate their own ideas or solutions to solve a problem.
Learning outcome for students when using STEM integration	Kathy	1. Helping students to become independent thinkers by using their own thinking to solve a problem.
		2. Helping students to see the connections among STEM subjects and to apply STEM knowledge.
		3. Helping students to use scientific knowledge and engineering design process. *(cont.)*

Categories	Participants	Patterns
(Table 11, cont.)	Lisa	1. Helping students to become independent thinkers by using their own thinking to solve a problem.
		2. Giving students an opportunity to apply their knowledge in real life situations.
		3. Helping students to understand ethical issues in real life situations.
	Carolyn	1. Understanding scientific concepts and the engineering design process are the two major goals.
		2. Helping students to distinguish the differences between science and engineering.
	Reese	1. Helping students to use what they have learned in a new way, such as applying their STEM knowledge.
		2. Helping students to understand ethical issues in real life situations.
	Sid	1. Helping students to engage in learning science and understanding the essence of science.
		2. Helping students to used their independent thinking skills.
		3. Helping students to relate to real-world problems.
Life skills	Kathy	1. Students learn how to deal with their frustration by solving a problem.
	Lisa	1. Students learn how to deal with their frustration by solving a problem.
	Carolyn	1. The redesign part in an engineering design process helps students understand the importance of endurance and persistence and to learn from failure while attempting to solve a problem.
	Reese	1. STEM integration helps students think differently in terms of failure.
	Sid	1. STEM integration helps students think differently in terms of failure.
Models of implementation of STEM integration	Kathy	1. Doing STEM integration really depends on which science units a teacher is teaching.
		2. Students need to learn content knowledge before they can do STEM integration.
		3. The best time to implement a STEM integration lesson is at the end of each big unit. *(cont.)*

Categories	Participants	Patterns
(Table 11, cont.)	Lisa	1. Depending on how STEM integration fits with the topic that a teacher wants to teach.
		2. STEM integration needs to address the science and engineering standards.
	Carolyn	1. Depending on the learning goals and also students’ STEM abilities.
		2. Connecting the science concepts that students have learned is important.
	Reese	1. Adding a small activity into different units cannot be considered using STEM integration meaningfully.
		2. Engineering is a glue to tie the other STEM subjects together. Engineering can act as a process to find a solution to a problem. Therefore students need to have content knowledge before they can do a STEM integration project.
		3. Mathematics is an afterthought in a STEM integration lesson.
		4. STEM integration is a very valuable assessment tool.
	Sid	1. It is important to integrate all the STEM disciplines. However, a teacher needs to be very flexible in applying STEM integration.
		2. Problem solving is a “have to” component in a STEM integration lesson. Therefore, students have to have some content knowledge before they can do STEM integration.
		3. STEM integration is like inquiry that cannot be used in everyday science teaching.
Issues or difficulties in implementing STEM integration	Kathy	1. Lacking the necessary technology to do STEM integration
		2. Students’ STEM ability
		3. Not sure how to design and implement STEM integration
		4. Too many class sessions
		5. Students’ motivation is a key to do STEM integration. It is hard to balance the fun and learning parts of a STEM integration lesson.

(cont.)

Categories	Participants	Patterns
(Table 11, cont.)	Lisa	1. Life science doesn’t lend itself to some parts of the engineering design process such as testing phase.
		2. A teachers needs to consider students’ abilities to design their STEM integration lessons, such as how much direction a teacher should give to his or her students.
		3. Students’ reading and mathematics skills have an influence on how to design a STEM project.
		4. Time issues
	Carolyn	1. A teachers needs to consider students’ abilities to design their STEM integration lessons, such as how much direction t a teacher should give to his or her students.
		2. Time issues
		3. Hard to balance the fun and learning parts of a STEM integration lesson.
		4. Integrating math into STEM integration lessons is difficult.
	Reese	1. Different subjects, such as chemistry and biology, can lead to different difficulties, when a teacher tries to design and implement STEM integration lessons.
		2. Students’ STEM ability
		3. Lack of experience can cause a teacher to not be sure how to design and implement STEM integration lessons.
		4. Too many class sessions can affect the quality of STEM integration lessons.
	Sid	1. Students’ motivation is a key to successful STEM integration.
		2. It is hard to assess what students learn in a STEM integration lesson.
		3. Time and resources are big issues when implementing a STEM integration lesson.
Others	Kathy	1. STEM integration provides opportunities for conducting student-centered learning.
		2. STEM integration helps students to open their eyes to see the connections among different STEM disciplines.
	Lisa	1. Students’ engagement levels are high in a STEM integration lesson. *(cont.)*

(Table 11, cont.)

Categories	Participants	Patterns
	Carolyn	1. STEM integration provides a better opportunity for students to work collaboratively.
		2. Students' engagement levels are high in a STEM integration lesson, and a STEM integration lesson is memorable to students.
	Reese	1. STEM integration can help students to become more sensitive about what is happening in the world.
		2. STEM integration can help students to practice their public speaking skills.
	Sid	1. STEM integration can help students to find their career interests.

CHAPTER 5

Cross Case Analysis and Discussion

This chapter intends to provide a cross-case analysis of the five participants. As mentioned in Chapter 3, the analytical procedure included: (1) open coding, (2) identification of patterns and categories, and (3) building themes for cross-case analysis.

In Chapter 4, the patterns and categories for each participant were presented. This chapter continues to use those patterns and categories that emerged in order to determine similarities and differences across the five participants to build themes for the cross-case model and to generate discussion about the five cases. The following nine themes were developed through the cross-case analysis and are discussed in detail in this chapter: 1) the focus of STEM integration is problem solving, 2) the focus of STEM integration is application, 3) the focus of STEM integration is engineering design, 4) the focus of STEM integration is developing life skills, 5) ethical issues are important in STEM integration, 6) the role of inquiry is very limited to process skills in STEM integration, 7) integration of mathematics into STEM lessons is difficult, 8) multiple strategies for integrating technology, and 9) perceived constraints to STEM integration that emerged from the data. In this chapter, each theme is presented in three sections, one section for each of the three research questions:

1. What are secondary science teachers' practices of STEM integration?
2. What are secondary science teachers' overall perceptions of STEM integration? and
3. What is the connection between secondary science teachers' perceptions and understanding of STEM integration with their classroom practices?

This organization will facilitate an understanding of teachers' practices, perceptions, and connections for each theme.

The Focus of STEM Integration Is Problem Solving

What Are Secondary Science Teachers' Practices of STEM Integration?

Problem solving is one of the primary ideas that emerged from teachers' practices of STEM integration. All of the five STEM integration lessons started with a problem or challenge. The problem/challenge tended to be open-ended and attempted to simulate real life situations. For example, Kathy asked her students to design an assistive device that could help people with special needs. She told her students "What engineers do is they find the problems or needs… For example, what your robot is supposed to do and how you can design an assistive device." Similarly, Lisa asked her students to create a genetically modified organism (GMO) that would be a benefit to society. She said, "How can you create a GMO that has a benefit to society? For example, maybe your organism can increase the quality of food." Reese, like Lisa, also asked her students to create a GMO that would be a benefit to society. She said, "In your group, you are going to use your own idea for your GMO…We are going to try to come up with an idea for a GMO that is going to solve a problem for our world or for certain people." Carolyn wanted her students to design a candy bag to hold the most candy. She said, "We start with 'what is our challenge?'" She asked students to write down the challenge and to design and build a candy bag that will hold the most candy without breaking or spilling the candy. Finally, Sid wanted his students to design a device that could protect an egg without breaking it when students dropped the egg from a height of 2 meters. He said, "Think how to build a device to protect your egg. You need to build something that can survive 2 meters." Sid told his students to think about this egg protection device as a vehicle and the egg that is inside the device as a human. He told his students to think about a car crash when they tried to design their egg protection devices by asking, “First, the egg protection device could not have a parachute... How is that an analogy to a car crash by not using parachute? The idea behind no parachute was to figure out a way to prevent collisions with materials.” It is important to note that all the problems were engineering design problems.

The teachers also wanted their students to relate their STEM projects to what a real scientist or engineer does on the job. For example, Kathy told her students to think like a real engineer by saying, “Engineers think, ‘What can I do to make it better to improve someone’s life,’” and “Engineers need to do research a lot of times. They need to do research to figure out what kinds of things have already been done.” Lisa said, “Genetically creating an organism is really expensive. It costs a million dollars to really create a GMO,” and “So that kind of scientific manipulating an animal or a plant has been going on forever. Farmers chose the strongest and the best animals to breed, and that is selective breeding.” Carolyn said, “Do you remember when we talked about the engineering process, we said one of the things an engineer does is to go find out what other people have already done?” and “For the engineering project, you are going to have some criteria and restrictions. For example, we don’t build an airplane without goals.” Reese explained to one group of students about how to conduct research by saying, “A lot of scientists have done this type of work already. Before you jump into this topic, you need to find out what things have been done already.”

There was a large portion of time in all the STEM integration lessons where students worked on their projects with their partners or team. The teachers rarely gave lectures. The teachers' roles were more like facilitators rather than instructors in all the STEM integration lessons. They wanted their students to use their own ideas to solve a problem. The teachers varied in the amount of guidance provided to students for developing a solution to the problem/challenge, with Carolyn giving her students the most directions when they were designing their solutions. Some of the teachers, such as Kathy and Sid, particularly stated that they really enjoyed not talking a lot in front of a class, but instead observing and helping students with their STEM projects.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

Problem solving was the most prevalent concept used by teachers to describe STEM integration. Kathy stated, "[STEM integration is] using your math, science, technology, and engineering knowledge to do problem solving," and "I guess when I think about STEM integration, it is kind of back to that problem solving." Lisa defined STEM integration as "an engineering way of thinking to come up with how to solve this problem." Carolyn articulated, "So you are defining a problem and you are trying to solve the problem."

The teachers had a tendency to associate STEM integration with real world problems. For example, Kathy said, "[In a STEM integration lesson] we talk about real life things and issues and we solve problems not just in schools or in textbooks, but in the real world." Lisa said, "STEM integration engages students in thinking about more real world aspects. It gives them opportunities to tie something into the real world." Through his STEM integration lessons, Sid wanted his students to understand in a real world situation that "an answer for a problem isn't always 'yes' or 'no', but rather 'good' or 'bad.'" Most of the teachers (Kathy, Lisa, Reese and Sid) believed solving a problem by using STEM integration could help students relate more to what real scientists do. Kathy said, "[When I integrate engineering] I just really try to focus on problem solving in a real world situation and to come up with different solutions." Lisa stated, "I think [STEM integration] feels more like real science. I think it gives kids many more real feelings about what scientists are doing as a career." Reese pointed out, "One of the focuses in my STEM integration lessons is how to make students really understand what scientists really do in their work," and "So, I think whenever you can give students as close to an authentic experience of what a scientist really does as possible, it helps them and they can actually get interested in it."

The teachers believed that incorporating problem solving into STEM integration helped their students become independent thinkers. Teachers valued that students were able to come up with their own answers and ideas. As Kathy pointed out, "When we do problem solving, I don't give them answers. I make them figure out the problem by themselves." Lisa said, "If I put STEM integration in [my lesson], I want to give the aspect of creating something to my students. I want [students] to use their imagination and creativity to create something." Carolyn believed that using problem solving in STEM integration gave students an opportunity to try new things and to internalize the ideas of what they did. She said, "So [STEM integration] gives them [students] chances to be more part of [the science]. It is like, 'here are some things and go make something out of it' without me giving them directions." Reese wanted to focus her STEM integration on how to pull together ideas and concepts that students have learned. She said, “So [students] actually apply and demonstrate what they have learned, not just recite or repeat what they have learned.” Sid believed teachers needed to help students become independent thinkers and that is how teachers should teach and students should learn. Sid stated, “[In a STEM integration lesson] it is more like, let’s tinker with it. Let’s play with it…Instead of me giving [students] directions, ‘Do this and do that,’” and “I would like you to know this rather than regurgitate it. You have to start coming up with your own ideas about what this is, about how this works.”

What Is The Connection between Secondary Science Teachers’ Perceptions and Understanding of STEM Integration with Their Classroom Practices?

There are strong connections between the teachers’ perceptions and classroom practices of STEM integration related to the role of problem solving in STEM integration lessons. The findings also suggest that teachers believed helping students to become independent thinkers and to be able to work on the project as a real scientist and engineer are valuable features embedded in the concept of problem solving within a STEM integration lesson. Both teachers’ perceptions and classroom practices suggest that the teachers considered problem solving as one of the most important elements when implementing STEM integration. One of the conflict points was that the teachers did not distinguish scientists and engineers in their STEM integration lessons. The problems or challenges that they gave to their students to solve were all engineering design problems or challenges. However, during interviews, some of the teachers (Lisa and Reese) mentioned that they wanted to give their students some authentic experiences as scientists when they do their work. This pointed out that some of the teachers might have misconceptions about science and engineering.

The term "problem solving" and "independent thinking" were used broadly by the teachers. Based on the data, problem solving and independent thinking could mean either a process, or skills, or both. For example, Kathy stated, "[STEM integration is] using your math, science, technology, and engineering knowledge to do problem solving." It is not clear if she referred to problem solving as a process that could help students connect STEM knowledge, or that STEM knowledge was used as skills to conduct problem solving or both. As for independent thinking, for example, Carolyn said, "It is like, 'here are some things and go make something out of it' without me giving [students] directions." From the data, it was not clear if she wanted her students to develop independent thinking ability or she wanted her students to practice independent skills. It is important to note that independent thinking highly relates to problem solving. Certainly, the findings suggested that problem solving and independent thinking are important elements that the teachers believed are needed to be included in STEM integration lessons. However it was not clear about the real role of problem solving and independent thinking in their STEM integration lessons. The teachers' explanations of how they viewed problem solving and independent thinking in STEM integration were not clearly defined. It was not clear if the teachers were using problem solving and independent thinking as a process, content knowledge, or context of the problem in most of the STEM integration lessons. For example, all the teachers gave students an engineering design problem or challenge for them to solve. In this case, problem solving could be referred to as a context. However, they also talked about how they wanted their students to become independent thinkers by using their own ideas to solve the problem. Therefore, problem solving was also used as a process in their STEM integration lessons.

As Carolyn said, “So you are defining a problem and you are trying to solve the problem…It is like, ‘here are some things and go make something out of it’ without me giving them directions.” It was not clear what role that “solve the problem” and “independent thinking” played in her STEM integration lessons. In addition, all teachers also had a hard time to explaining the characteristics of problem solving and independent thinking.

Another interesting conflicting data point between perceptions and implementation of problem solving in the STEM integration lesson occurred in Carolyn’s case. She intentionally set up a very tight budget to limit the materials that students could acquire. This also restricted students’ creativity in designing their candy bags. Because students only had very few degrees of freedom to design their candy bags, most of the students ended up with very similar designs. Carolyn explained that if most of students had very similar designs then this would help her to teach the mathematics (volume and mass) more easily than if she had to deal with a variety of designs. This deliberate implementation decision contradicted her stated purpose of STEM integration being to develop students’ independent thinking.

In contrast, Lisa let her students be completely in charge of decisions for the GMOs that they wanted to create. In her Genetic Engineering activity she emphasized creativity and imagination. Students came up with various GMOs that they wanted to create. Some of the GMOs that students wanted to create were conceptually impossible through genetic modifications. For example, a group of students wanted to create a cow that could produce Coca-Cola and another group wanted to create a woman with an Afro that could turn into a pencil sharpener. Both the Coca-Cola and pencil sharpener ideas did not have any gene that students could implant into another organism to create a new GMO. However Lisa did not address this issue in her Genetic Engineering activity. By putting a focus on creativity, Lisa lost sight of the content in her STEM integration lesson.

Teachers struggled to find a balance between how much freedom they should let their students have with their STEM integration lessons and how much structure to incorporate into the activity.

The Focus of STEM Integration Is Application

What Are Secondary Science Teachers' Practices of STEM Integration?

When implementing problem solving, teachers specifically wanted their students to apply their existing STEM knowledge to solve the problem/challenge. Kathy said to her students, "You are going to use science and math skills to help you brainstorm your possible solutions. You also need to use your imagination. You have to be creative to design your own things." Lisa said to her students, "Before the break, we talked about what genetic engineering is. Today you are going to invent your own genetically engineering organism…The idea is for you to think creatively when you come up with your own genetically modified organism." Carolyn wanted her students to think about the math they had already learned that could help them measure the weight of their candy bags. She reminded them of what they had already learned in an earlier lesson and recommended that they go back in their notes to see how to measure weight and mass. Before Reese let her students start work on the Genetic Engineering project, she wanted her students to think about what they had learned about GMOs by saying, "Give me some names of GMOs and why are they modified or what's the problem or the issue that the creators tried to solve?" Sid reminded students about the science concepts of force, collision, and momentum that students learned at the beginning of his Egg Drop project by saying, "We are trying to make force stand for a long period of time so that it gets smaller. We also still need to change the momentum in the some way," and at the end of the class, "I hope you have a better idea about collision and momentum. This is what this project is all about." One of the purposes for all the STEM integration lessons was to help students connect and apply their prior STEM knowledge.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

In order to problem solve in STEM integration, all teachers believed that students needed to first acquire content knowledge such as science and mathematics, and/or technology skills before they could solve a problem. Kathy said, "I love to be able to teach science and maybe some of the math. Then do some sort of engineering projects that use those." Lisa stated, "[Science] content knowledge is my major focus in a STEM lesson. Surrounded by that, I add more STEM disciplines." Carolyn described, "I start with the science concepts that we are covering… Then there are the big ideas about how you could tie this up with engineering. How can we make some sort of product?" Reese stated, "Science probably is the biggest part of [STEM integration]. If there is any mathematics involved that would be more at the beginning. Engineering is usually kind of the last piece where students come up with their own project." Sid pointed out, "So, we learn math and science. We learn the process. We learn how to use this tool, technology. Now we have a problem. Do the math, do the engineering, use the technology and apply the science to solve this problem," and "[Students] need to have something concrete to attach a concept to. I think that is where the integration comes in."

Teachers, who wanted their students to learn content knowledge and/or technology skills before solving a problem, explicitly made the aspect of application one of the unique qualities for STEM integration. Kathy said, "I just like that [students] can go back to apply [content knowledge]." Lisa pointed out, "STEM integration makes students understand the concepts that had been taught in class on a different level. It is like how you solve a problem in real life by using the content knowledge that you have." Carolyn expressed her view by saying, "So [students] can apply the scientific concepts that we have been doing in an engineering situation." Reese described, "STEM integration is like a process. A process that I can use to teach my students how to apply what they have learned into a new and comprehensive level." Sid said, "To me, STEM integration is finding ways to give more opportunities to students to solve actual problems in my class, and you have to fully integrate all content into one."

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The evidence suggests that teachers' perception and classroom practices are aligned in this theme. The teachers wanted their STEM integration lessons to be able to help students apply and connect their prior STEM knowledge in an engineering context. However, regardless of how big or small a STEM integration lesson was, all the teachers believed that application was one of the important features that needed to appear in a STEM integration lesson, and students needed to have certain science content knowledge, mathematics, and technology skills in order to understand the meaning of doing STEM integration.

The focus on application led Lisa, Reese, and Sid to implement a culminating project for their STEM integration unit. A culminating STEM integration project served two different purposes: to review and/or reinforce the scientific concepts students learned (Lisa and Reese), and to act as a bridge to transfer scientific concepts from one unit to another (Sid).

Lisa and Reese used their Genetic Engineering activity/project to review and reinforce what students had learned from their genetic unit/biotechnology course. They placed their Genetic Engineering activity/project at the end of a unit/course. Lisa said, "With genetic engineering, it is part of a big genetic unit. I just want to use that project to introduce what genetic engineering is to my students," and "[The Genetic Engineering activity] engages [students] to learn science. It also helps them to connect what they had learned before." Reese stated, "[The Genetic Engineering project] ties everything together, everything that we had talked about in the semester. Kids need to think about what scientific knowledge or information they have to use," and "In [the genetic engineering] project, students need to come up with their questions and use their knowledge in a new way."

As for Sid, he used his Egg Drop project as an introduction to the transition from his momentum lesson to the energy unit. The Egg Drop project helped prepare students for encountering new science content in the next unit while at the same time reinforcing concepts learned in the previous unit. Therefore, he placed the Egg Drop project between the end of his momentum lesson and before his energy unit. He said, "It [the Egg Drop project] was not only a good end of the unit that we just did with the momentum. It also transitioned as well to energy which we are talking about now."

The Focus of STEM Integration Is Engineering Design

What Are Secondary Science Teachers' Practices of STEM Integration?

Elements of the engineering design process could be observed in all five STEM integration lessons, although the enactment of engineering design differed between middle and high school teachers. The middle school teachers specifically implemented engineering design as a step-by-step process and explicitly introduced engineering design to their students. On the other hand, while using engineering design in their STEM integration lessons, the high school teachers did not explicitly discuss the design process with their students or even inform them that they were using an engineering design process.

For example, Kathy said to her students, "Today we will begin to understand the engineering design process. We have talked a little bit about the engineering design process before, but now the engineering design process is going to take up this course for the whole quarter," and "You are going to do a lot of planning today and maybe a little bit of research. Then, you are going to go step by step to figure out how you are going to do your whole robotics lesson." Lisa also had a packet that contained step-by-step questions to guide students to complete her Genetic Engineering activity. She also taught this activity by guiding students step by step through the engineering design process. She said, "We are going to continue the research phase of your project…This is step 2, the research phase…Once you come up with ideas together with your partners, you need to move on to step 3, designing your organism." Carolyn explicitly told her students that the Candy Bag activity is an engineering project by saying, "This is an engineering project. You are going to design and build a better candy bag." When Carolyn wanted her students to examine different bags, Carolyn said to her students, “Do you remember when we talked about the engineering process, we said one of the things an engineer does is to go find out what other people have already done?”

As for the high school teachers, Reese conducted her Genetic Engineering project by simulating what a genetic engineer would do to create a GMO. Reese started her Genetic Engineering project by giving students a challenge, which is the first step of the engineering design process. After she gave the challenge to her students she said, “First, you are going to think about a problem…the rest of the hour will be for you to think about what and how you want to do your project.” Her implementation of engineering design focused more on the planning phase rather than the testing phase. In her Genetic Engineering project, she asked students to think about a problem, to conduct research, and to make a plan for how to genetically modify an organism. This is highly associated with what a real world genetic engineer would do, which is to construct a plan before actually genetically modifying an organism. However, she did not explicitly inform her students that they were using an engineering design process.

Although Sid did not explicitly discuss the engineering design process in his Egg Drop project, he employed it by asking his students to draw one or two prototypes to show their egg protection devices and to calculate their budget sheet, as well as providing constraints such as no parachutes, limited materials, and limited testing capabilities. Furthermore, he also asked students to test their egg protection devices and use that information to redesign a better egg protection device.

All of the STEM integration lessons involved a hands-on final product, such as a physical product or a poster. For example, the final product for Kathy’s Robotics unit was a Lego robot that could help certain people. Carolyn asked her students to design a candy bag as the final product for her Candy Bag activity. An egg protection device was a requirement for students to pass Sid's Egg Drop project. As for Lisa and Reese, instead of creating a product that students could test, they asked students to do a poster or presentation that students could use to present their ideas in front of the class as the final product.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

When teachers were asked how they integrated each STEM subject into their STEM lesson, all the teachers had confidence that they integrated engineering into their STEM integration lessons. Kathy stated, "[The Robotics unit] was kind of a stand-alone engineering type of lesson…The engineering part was definitely following the engineering design process, which is tied to sixth-grade science standards…" Lisa described her method for using engineering in her Genetic Engineering activity by saying, "Engineering was the part that I asked [students] to use engineering design to create their GMOs." Carolyn defined her way of using engineering in her Candy Bag activity by saying, "Engineering was the engineering design process, which was in the sixth-grade standards." Reese described her strategy to integrate engineering in her Genetic Engineering project by saying, "Engineering comes at the end where [students] came up with their own project." Sid defined his method of integrating engineering by saying, "[Students] just learned momentum and collision. I wanted to tie these concepts to an engineering design project."

When asked about the focus of STEM integration, all of the middle school teachers (Kathy, Lisa, and Carolyn) mentioned the engineering design process. Kathy used her Robotics unit as an example and explained, “I think the engineering design process is very important when I teach STEM integration. [The engineering design process] leads to problem solving.” Lisa believed, “Using the engineering process to create your own unique solutions to a problem is a key to STEM [integration].” Carolyn stated, “I think that the cyclical nature of [the engineering design processes] is really important for [students].” The middle school teachers believed their students needed to learn and practice using engineering design process. They also pointed out that their students are accustomed to following directions both from teachers and textbooks. Therefore students need to learn and practice using their own ideas to solve a problem. This also ties back to the fact that teachers wanted to help their students develop and practice their independent thinking skills. For example, Kathy said, “I like to leave things open-ended so that [students] can do their lab to try to make their own things, and to create and to be creative by using these steps [of the engineering design process].” Carolyn said, “[Students] have to be trained how to think independently. A lot of them are not used to there not being a right answer. [The engineering design process] helps them to do problem solving by using their own ideas.”

On the other hand, while Reese and Sid did not specifically address engineering design during the interviews, they did emphasize the importance of integrating engineering in STEM integration. One of the biggest reasons that Reese believed her Genetic Engineering project was a successful STEM integration lesson was because she tried to integrate both science and engineering. She said, “I felt like because I am emphasizing the engineering aspects that is what made this [Genetic Engineering] activity a STEM integration project.” As for Sid, he believed engineering was a part of

STEM integration. Sid stated that in STEM integration science was the knowledge behind it; engineering was the process of doing it; math was the tool to give the quantity to it; and technology was what comes out of it. To have an ideal STEM integration lesson, he needed to integrate all the STEM subjects. He said, “To me, totally integrating STEM is making it systemic.” Therefore, when he talked about STEM integration, he did not place a lot of effort into talking solely about engineering.

Hands-on work was another concept that was embedded in engineering design. Most of the teachers believed that by implementing STEM integration, students had opportunities to really turn their ideas into a concrete product. For example, Kathy said, “[Students] do engineering-type labs or projects because they need to practice that over and over again. In that way they can use what they know about science and math to figure things out and do engineering things.” Although Lisa could not really ask students to create a GMO, her students still needed to create either a poster or a craft in her Genetic Engineering activity. She said, “I have to modify the part of the engineering design process that we cannot actually do. Instead of doing the testing phase in an engineering design process, we do discussion at the end,” and “[Students] are creating. It is not necessarily going to match what everybody else does. They can come up with absolutely anything.” Sid believed a hands-on activity that had a problem that needed to be solved was a vital component. He valued the “trying” phase, such as testing different materials or solutions to find out the best answer, in a STEM integration project. He said, “[A STEM integration project] is the idea of manipulating a project so [students] actually have to physically try it. That makes them learn,” and “I think kids need to tinker. I think they need to touch things, play with things and realize they just have to explore the answer by trying their ideas or experimenting with different materials."

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The evidence showed that the engineering design process was common to middle school teachers' perceptions and practices of STEM integration. One reason was that all the middle school teachers believed that their students were not familiar with the engineering design process. Therefore, they needed to guide their students to use the engineering design process step by step.

Another reason could be traced back to the Nature of Science and Engineering standards. Kathy used her Robotics unit as an example and said, "…The engineering part was definitely following the engineering design process, which is tied to sixth-grade science standards…After the lesson, I can check [the engineering design process] off my list." Lisa stated, "Since the science standards have changed this year, most of my time is devoted to changing what I have been doing to fit the new standards." Carolyn described how she designed her STEM integration lesson by saying, "I start with the science concepts that we are covering, because sixth grade has these benchmarks that need to be hit. Then there are the big ideas about how you could tie this up with engineering," and "[Engineering] is one of the sixth-grade standards. We have no choice. I am [teaching the engineering process] sort of for the sake of the standards."

This focus on engineering design directly related to introducing the concept of engineering design. Kathy believed her Robotics unit was particularly focused on engineering. She said, "[The Robotics unit] was kind of a stand-alone engineering type of lesson," and "For the Robotics unit specifically, that one is following the state standards' engineering design process." Carolyn had an idea of implementing a STEM integration lesson as culminating project by saying, "My plan is that for every big scientific concept that we cover this year, we will have some project toward the end of the unit…that can apply the scientific concepts that we have been doing in an engineering situation." Yet, her Candy Bag activity is an engineering-only lesson. This could be tied back to the fact that the middle school teachers felt that their students need a lot of practice in applying engineering design process. Carolyn used her Candy Bag activity at the very beginning of an academic year to introduce the engineering design process. She wanted her students to be aware that they would be using this process throughout the entire year.

Although the teachers understand that engineering design did not mean that they needed to have a hands-on product, they preferred to have one. For example, Kathy said, "I think a lot of people have this mentality that when you think about STEM, you think like a hands-on project, but I know that a hands-on project is not necessary for STEM." However, in her Robotic unit, Kathy asked students to create a robot as their final project, which was a hands-on project. Also, Sid said, "[A STEM integration project] is the idea of manipulating a project so [students] actually have to physically try it. That makes them learn." The hands-on work of a STEM integration project was shown as one of the important elements in their STEM integration lessons. Overall, all of the teachers believed that applying engineering design was one of the goals for their STEM integration lessons. They all emphasized the "doing" part in their STEM integration lessons. The teachers used the engineering design process as one of the main concepts to design their STEM integration lessons. A hands-on project ("physically doing it") is one of the most distinguishing features in their STEM integration lessons, such as following step by step to design a product.

Three main points emerge from this theme. First, teachers considered engineering design as a necessary feature of STEM integration and engineering design was highly associated with problem solving. Second, the Nature of Science and Engineering standards drove teachers' perceptions and classroom practices of STEM integration to place more focus on engineering design. Finally, engineering design implied a hands-on project to the teachers. By actually creating a hands-on project, the engineering design process serves a purpose as a framework to solve a problem in all the STEM integration lessons.

The Focus of STEM Integration is Life Skills

What Are Secondary Science Teachers' Practices of STEM Integration?

During the observation, the researcher did not perceive and observe anything that was related to life skills. After teachers mentioned life skills during their interviews, the researcher went back to the observation data and tried to identify what the teachers implicitly did in their practice of STEM integration was related to life skills. Therefore, the description in this section is based on teachers' view of what they implicitly did in their classroom that relate to life skills.

From the teachers' view, this theme is highly related to the concept of helping students to become independent thinkers. In all the STEM integration lessons, teachers encouraged students to use their own ideas and to try different solutions to solve the problem. They believed the process of trying to solve a problem in their STEM integration lessons helped students realize that their failure trails could guide them in the right direction. Students could see the value of their failures. In order to be successful, they needed to keep trying and not be afraid of getting an answer that is not what they want. This particularly could be observed in the physical science teachers' STEM integration lessons. For example, Kathy told her students that it is perfectly all right if they come up with many different solutions to design their robots. Also, during the day of programming a robot, Kathy told her students, "You get to decide what your robot will do. So just explore the options in the program and think about what you want your robot to do." Carolyn also encouraged students to examine the materials that she provided before they decided how to design their candy bags. She said, "If you need to take a look at the supplies before you start to design your bag, you can come to me and I will show you them." During the redesign day of her Candy Bag activity, she again encouraged her students to think of different ways to design their candy bags by saying, "Maybe you have a bag that is really strong, but really small. How can you change your design to make it hold more?" Sid encouraged his students to think about different solutions for his Egg Drop project. He reminded students that they should try to build the cheapest device that would allow their egg to survive a fall from a height of 2 or more meters. He said, "The groups that think the most, the hardest, generally do better. You have to plan ahead and that is what you need to work on." Another example was that when a group dropped their device, they checked their egg and discovered a crack. The group told Sid what happened and he said, "Now, go back to thinking more, like where can you change your design."

In their STEM integration lessons, teachers encouraged students to keep trying and thus students realized that if things did not work the way that they planned or if they did not get the answer they wanted, they just needed to keep trying different ideas. During observations of STEM integration lessons, students seemed very excited and not afraid to try their own ideas.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

All of the teachers believed that STEM integration could teach their students some life skills that they needed to know beyond the science classroom. The teachers believed that in a STEM integration lesson their students were more willing to try any idea that came to their mind because they knew they were not looking for a correct answer but rather the best answer for a problem. Carolyn, Reese, and Sid particularly mentioned that STEM integration lessons helped their students think differently about failure. Carolyn suggested, "Learning from mistakes/failures is a good life skill for them, not giving up and understanding that it is OK if it does not work out this time… [A STEM project] gives [students] good life skills in terms of not giving up." Reese stated, "[Students] don't see the value if things don't work the way that they planned. I think this is one of the biggest downfalls of the kids," and "The STEM [project] helps them to see the value that you just have to keep trying." Sid said, "I want [students] to know it is all right to have an answer that was not what they expected," and "I want [students] to try. It is the process that helps you learn. Those are the things that they need to understand, even after they leave school."

As for Lisa and Kathy, they stated that their students felt frustrated when they were not able to solve a problem. Kathy said, "[Students] did get really frustrated, but they also felt a huge sense of accomplishment when they actually got something done." Lisa said, "[STEM integration] is like life skills—dealing with a problem and dealing with their frustration. [STEM integration] is working through their [students'] frustration level." Kathy and Lisa believed that problem solving in STEM integration helped students learn how to work through their frustrations by trying different ideas.

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The teachers' perceptions correspond with their classroom practices in this theme. They wanted their students to think through different solutions for the problem that they needed to solve. In their classroom practices, the teachers encouraged students to try their own idea to solve a problem/challenge. Even when students created a product that could meet the challenge, they asked students to think more and try different solutions. The teachers believed that the thinking and trying process of a STEM integration lesson, which highly relates to engineering design, could help their students think differently about failure. The hope for these teachers was that implementing STEM integration could help their students be able to deal with circumstances they might consider as failure in their lives.

Overall, all of the teachers believed a STEM integration lesson naturally created a learning environment that helped students to pursue persistence and endurance when they tried to solve a problem. Dealing with failures and frustrations are important life skills that students need to develop and master even if they do not choose a STEM field for their future career path.

Ethical Issues Are Important in STEM Integration

What Are Secondary Science Teachers' Practices of STEM Integration?

The life science teachers, Lisa and Reese, included ethical issues as one of the important elements in their STEM integration lessons. Lisa asked students questions about ethical issues that related to genetically modifying an organism. She also showed a film about how genetic engineering helped agricultural production systems in California. The film had information on how GMOs benefit agriculture in California and why is important to be aware that some people think GMOs are bad for our society. Reese specifically included ethics in the GMO project rubric that she gave to her students. In fact, ethics was one of the most important categories accounting for 25 points out of 100. She wanted her students to think about the ethical, legal, and moral implications of GMOs as she implemented her Genetic Engineering project. She said, "So, I gave you the outline that you need to cover…I will maybe focus on some highest points, like ethics or how you are going to get the gene into your organism."

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

During their interviews the two life science teachers talked about wanting their students to be aware of ethical issue in real life situations. For example, Lisa considered ethics to be an important aspect that she should bring up when she taught her Genetic Engineering activity. She said "[Students] have to talk through some questions, such as is this [GMO] really a true benefit to society? They have to really think about it because they are messing with genes." Reese also showed the same concerns as Lisa about ethical issues in genetic engineering. She wanted her students to understand that every decision they make has a consequence, especially in the biotechnology field. She said, "I focus a lot on the ethics and the outcomes. I want kids to think about, 'OK, if this [genetically modified organism] actually happened, how would that affect the environment or the people and the world?"

In contrast, the physical science teachers did not voice this concern. Ethics was not mentioned in their interviews. It seemed that ethical issues were a major focus in STEM integration lessons only for life science teachers.

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The findings suggest that the life science teachers' perceptions and classroom practices are aligned for this theme. The life science teachers included ethics as one of the foci in their STEM integration lessons. They also explained why ethics is important and what they wanted their students to be aware of it in their Genetic Engineering activity/project. During their classroom practices both Lisa and Reese explicitly told their students that they needed to take ethical issues into account when they designed their GMOs.

It is important to note that the Nature of Science and Engineering standards lists the interactions among science, technology, engineering, mathematics, and society as one of substrands that teachers need to address in their classrooms. For example, eighth-grade students need to be able to explain "how scientific laws and engineering principles, as well as economic, political, social, and ethical expectations must be taken into account in designing engineering solutions or conducting scientific investigations regardless of what subject a science teacher teaches (p.23)." Also, high school students need to "describe how values and constraints affect science and engineering, such as economic, environmental, social, political, ethical, health, safety and sustainability issues (p.24)." Therefore, regardless what subject—such as life science or physical science—a teacher teaches, he or she should be aware that the interactions among science, technology, engineering, mathematics, and society are important in STEM integration.

The Role of Inquiry Is Very Limited to Process Skills in STEM Integration

What Are Secondary Science Teachers' Practices of STEM Integration?

This theme particularly relates to physical science teachers. During classroom observations, the researcher did not observe any activities or specific actions that could be ascribed to inquiry as defined in the National Science Education Standards (NRC, 1996). Therefore what is presented in this section is what the physical science teachers believed to be inquiry in their STEM integration lessons. From their view, the use of inquiry is highly related to problem solving and hands-on work practices. The evidence that inquiry is highly related to problem solving and hands-on work practices did not show in their classroom practices but during their interviews. The teachers did not mention anything about inquiry to their students. In their classroom practices, the teachers asked students to conduct research and to test their designs during their STEM integration lessons. Instead of giving out the correct answers, the physical science teachers asked their students to do research or to talk to their partners to find the best answer or solution for their problem when they were designing or creating their products.

In their STEM integration lesson the teachers wanted their students to generate their own ideas/solutions to solve a problem and to design or create a hands-on project. By not giving students a concrete answer or solution, teachers encouraged students to explore the possible solutions for themselves. When students explored the possible solutions, they needed to use their prior knowledge and creativity to evaluate the usefulness of their ideas by applying them to design or by creating a project. The teachers considered the thinking process that involved creating a final engineering product as inquiry. However, from the researcher's view, the teachers' actions in their STEM integration lessons could not be considered scientific inquiry.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

Inquiry was one of the indistinct concepts that emerged from the interview data. All of the physical science teachers (Kathy, Carolyn, and Sid) discussed inquiry (science) and the engineering design process or engineering when they talked about STEM integration.

Their interview data suggest "inquiry" is why they constructed their STEM integration lessons the way they did. From their interviews, the teachers seemed to consider inquiry as part of problem solving (Kathy, Carolyn, and Sid) and also science content (Kathy and Carolyn). Kathy said, "In my class, with engineering, we try to do a lot of inquiry stuff with problem solving," and "I really do like the strengths [of STEM integration] being problem solving. I like to have kids do a little inquiry, thinking on their own, and not always getting the answers," and "The science was basic, like inquiry, like the problem solving and building and trying to figure out how to put the robots together." Carolyn used her Candy Bag activity as an example and said, "I think the strongest piece in science is exactly the inquiry piece, when [students] try to answer the question: what's good and bad about different bags? That is inquiry, the science skills." Sid concluded, "I think just overall, [a STEM integration lesson] is a better way to introduce inquiry and to show [students] that the philosophy of science is all about problem solving. It is about thinking." Kathy and Sid compared STEM integration to inquiry by stating that teachers cannot use it every day because some science concepts a teacher just has to explicitly teach. This is also likely related to the class time required to do scientific inquiry and engineering design meaningfully. Kathy said, "[STEM integration] is like inquiry. You cannot use inquiry all the time in your class. Some things you just have to explicitly teach, like what force is." Sid reiterated this concept by stating, "[STEM integration] is like inquiry. You can't do this every day. You do have to eventually tell [students] the answers. You can't just make them guess." It is interesting to note that the teachers considered inquiry as both science content and a process of learning in a STEM integration lesson.

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The evidence pointed out that all the physical science teachers believed that when students "think" about how to solve an open-ended problem that the thinking part is inquiry. These teachers also believed that solving a problem is the ultimate goal both in inquiry and engineering design. Some of the teachers (Kathy and Carolyn) particularly used inquiry as science content in their STEM integration lessons.

The teachers' view of inquiry was limited to process skills in their STEM integration lessons. Their classroom practices and perceptions suggest that these teachers have a limited or naïve view of scientific inquiry. Much of the evidence suggested that the teachers did not distinguish science from engineering. For example, Kathy said, "Scientists and engineers do things for a reason. It is like they have problems that need to be solved." Lisa said, "The engineering and science parts to me meld very well together.

The processes of doing science and engineering are very similar. It is about solving a problem." Carolyn articulated, "[Engineering] has a similar process to what we see in science. So you are defining a problem and you are trying to solve the problem" and "Science and engineering are sort of working hand in hand. The idea of defining a problem, trying to solve the problem, testing things, and using results—those are the sort of areas where science and engineering really overlap." As is evident from these quotes, the teachers considered problem solving as a place where science and engineering overlap. For these reasons, the teachers believed that scientific inquiry is part of problem solving and the goal of engineering design.

If the teachers consider scientific inquiry and engineering design as processes to solve a problem, they do share some common knowledge, such as asking a question in science versus identifying a problem in engineering. However the essence of science and engineering are different. Scientists try to understand and explain the natural world. Engineers apply knowledge to solve practical problems within the human-made world. Most importantly, the question that a scientist would ask is different from the engineering design problem that an engineer would propose. For example, a scientist may want to find out why the wind blows. Yet an engineer may want to create a device to capture the wind in order to generate electricity.

Although all of the STEM integration lessons started with an open-ended problem or challenge, the open-ended problem or challenge was an engineering design problem or challenge. None of the teachers provided a scientific question for their students to think over. The evidence suggested that the teachers used the words scientists and engineers interchangeably. For example, although Reese gave her students an engineering design problem to solve in her Genetic Engineering project, during the interview she said, “One of the focuses in my STEM integration lessons is how to make students really understand what scientists really do in their work.” Lisa also gave an engineering design problem in her Genetic Engineering activity and during her interview she said, “I think [STEM integration] feels more like real science. I think it gives kids many more real feelings about what scientists are doing as a career.” The teachers wanted to simulate what a real world scientist or engineer does for his/her job by giving their students a problem to solve. However all of the teachers gave their students an engineering problem, not a scientific question. Consequently, when the teachers talked about inquiry, it was as related to critical thinking or a process skill within an engineering design context. This issue may arise because of limited views of scientific inquiry as process skills in their STEM integration lessons or because of misconceptions about the difference between science (scientists) and engineering (engineers).

Integration Mathematics into STEM Lessons Is Difficult

What Are Secondary Science Teachers’ Practices of STEM Integration?

When mathematics was integrated, it was primarily used as a tool in a STEM integration lesson. For example, in Carolyn’s Candy Bag activity, she used mathematics as a tool to help students measure the volume of the candy bags. In her class, she wrote down the mathematical equation for calculating volume on the whiteboard and asked students to measure the length, width, and height of their candy bags. By plugging their measurements into the equation, students would be able to calculate the volume of their bags. Carolyn also asked students to figure out the engineering budget for their candy bags before they could actually build them. Students needed to use their mathematical skills, such as addition and subtraction, to calculate the budget. Sid also asked his students to map out their engineering budget while they were designing their egg protection devices. This was the only evidence that could be found in Sid's Egg Drop project of mathematics integration.

Kathy was the only teacher who used mathematics in a different way. She integrated mathematics by asking students to program their robots, which is mathematical modeling using logic commands. Students needed to have a systematic way of thinking first, and then drag the function icons into their computer dialog box to test the function of their robots. This process could be considered creation of a mathematical model because it depended on what students wanted their robots to do and to use different computer icons to program them. However when she explained to her students how to program their robots, she did not explicitly connect what students did with the mathematics.

As for the life science teachers, Lisa and Reese, no evidence was found that they integrated mathematics in their STEM integration lessons.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

All of the participants indicated that mathematics is very important and needs to be integrated into a STEM integration lesson. For example, Kathy said, "[In a STEM integration lesson] I love to be able to teach science and maybe some of the math. Then, [students and I] do some sort of engineering project that uses those [science and math concepts]." Lisa stated, "Math is very important to STEM integration. [STEM integration] needs a mathematical part to it as well. It is like getting [students] to think numerically as they work through the process." Carolyn believed that STEM integration could provide a real world context that could help students to use their mathematics skills. She said, “Using their math skills in a real world context, I think that is great. STEM can provide a real world setting for [students] to use their math skills.” Sid stated, “I guess my ideal [STEM integration lesson] should include all aspects [of STEM subjects].”

However when teachers were asked how they integrated mathematics into their STEM lessons, all the teachers, except Carolyn, believed that there was not a lot of mathematics involved in their STEM integration lessons. Kathy said, “The math was kind of lacking in [the Robotics unit].” Lisa said, “I don’t think there is a lot of math in [the Genetic Engineering activity].” Reese said, “I think in this [Genetic Engineering] project, we did not have any math in it.” Sid said, “I don’t think there was a lot of math involved in [the Egg Drop] project.” On the other hand, although Carolyn was the only teacher who with confidence said that she integrated mathematics into her Candy Bag activity, she was convinced that she did not do a good job on integrating mathematics into her STEM integration lessons. She said, “That [math] part in my Candy Bag activity, I always felt it was not very accurate. But I didn’t know how to change it,” and “I wish I could figure out a way to modify the measurement piece, so [the math part] was easy enough for [students] to do. Or, maybe I should just not worry about [the math part].”

In general, most of the teachers believed that mathematics was already embedded in science. Kathy said, “We do a lot of graphing in science to help strengthen math skills…So, [students] were able to use the math…not so much basic math skills, but more like analytical math…” Lisa pointed out, “Mathematics naturally falls into [science], if you are dealing with data.” Carolyn believed that science and math paired well together and this pairing naturally happens often in physical science. She said, “We do measure things, and we make graphs and analyze data…So that [math] piece is kind of given. [Math] gives that quantity piece to [STEM integration].” Sid stated, “The nature of math in science means application of concepts. An idea to show them [students] it [a solution for a problem] works.” Reese believed, “[Math] is a tool. For example, in chemistry you need to solve an equation or we do graphing, so that is where the math comes in.” However, Reese was the only teacher who also believed that if she could not give a new meaning to mathematics in her STEM integration lesson, she did not integrate mathematics in STEM integration. She said, “Particularly, math is in [chemistry] already. I don’t think emphasizing the math in stoichiometry is STEM integration. I don’t think that really adds to the course.”

What Is The Connection between Secondary Science Teachers’ Perceptions and Understanding of STEM Integration with Their Classroom Practices?

The evidence suggests that all of the teachers believed that mathematics is an important element and that they needed to integrate it in a STEM integration lesson. Except for Reese, most of their classroom practices showed that their STEM integration lessons integrated mathematics, at best, in a very limited way, such as to use it as a tool, or not at all.

Naturally, besides Reese, teachers had a perception of using mathematics in a very algorithmic way in their STEM integration lessons. Therefore, in general, the teachers treated mathematics as a tool to help students collect scientific data and/or to calculate an engineering budget in their STEM integration lessons. An important idea to note is that Kathy did integrate mathematics in her Robotics unit by asking students to program their robots. However, she did not recognize the mathematical thinking required in her STEM integration lesson, suggesting a limited understanding of mathematics.

Although the teachers all considered mathematics as an important part of STEM integration, most of the teachers (Kathy, Lisa, Reese and Sid) were convinced that they integrated very little or no mathematics in their STEM integration lessons. Even Carolyn, who was the only teacher who believed that she had integrated mathematics, did not believe that she had done a decent job of integrating mathematics into her STEM integration lesson. One of the explanations could be that these teachers are science teachers and their job is to teach science, not mathematics. Therefore they tend to use mathematics as a tool to solve a problem in their STEM integration lessons. For example, Kathy stated that in a STEM integration lesson, students "can problem solve the science and also be able to use the math, that actually focuses on the problem solving in science." Lisa said, "This is a science class. We were never creating mathematical solutions that often. So, mostly, I use math as a tool." Carolyn said, "For me, it is more of an added bonus to get some math in here, rather than I have to teach this math concept."

Another reason could be that integrating mathematics in science is very context specific. For example, although Lisa did not integrate any mathematics in her Genetic Engineering activity, she provided an explanation that she could not find a way to integrate mathematics in her Genetic Engineering activity without feeling that she was forcing it. As a result, she chose not to integrate mathematics, although she could use Punnett Square in her Genetic Engineering activity. She said "My kids have learned Punnett Square and predicting probability in my gene unit, but I didn't have them using Punnett Square in the [Genetic Engineering] project. I just think it really cannot fit into the project." Therefore, the contexts had influence on how the teachers implement mathematics into their STEM integration lessons. Consequently, what the researcher had observed might be insufficient to draw conclusions of how the teachers used mathematics in their STEM integration lessons.

It was hard to judge if the use of mathematics as a tool could be considered integrating mathematics in a STEM integration lesson. To judge this question, a researcher also needs to take the context of a STEM integration lesson into account. For example, maybe a reasonable way of integrating mathematics is using it as a tool in the Candy Bag activity. Also, just as what Lisa stated, there may not be room for mathematics in the Genetic Engineering activity. There are many factors that would influence how the teachers make their decisions to integrate mathematics in their STEM integration lessons. Yet to most of the science teachers it seemed enough to use mathematics as a tool to help students solve a science or engineering problem, because most of them believed that mathematics is naturally embedded in science already when asking students to collect data or create graphs.

Multiple Strategies for Integrating Technology

What Are Secondary Science Teachers' Practices of STEM Integration?

The integration of technology occurred in two different ways in the STEM integration lessons. The products that students designed, being technologies, represented one method of technology integration. On the other hand, teachers and students were using different technologies, such as pencils, markers, Legos, Styrofoam, rulers, scales, tape, glue, scissors, and computers as tools to help them to do research or to build their final products. Technology appeared in all of the STEM integration lessons in 1 of these two forms. For example, in Kathy's Robotics unit and Reese's Genetic Engineering project, students used computers to do research on what assistive devices are and to program their robots, or what GMOs that they wanted to create to benefit our society. Although Lisa did not explicitly tell her students that a genetically modified organism is technology, she did integrate technology in her Genetic Engineering activity. For example, her students were using color markers to draw their final posters. Some of her students brought different materials such as Styrofoam, beads, and cotton balls to build their GMOs. Carolyn and her students used scales and rulers to measure the length and width of their candy bags. Kathy wanted her students to build their final products by using a Lego kit. Sid instructed his students to use the different materials that he provided to build their egg protection devices. However none of the teachers made explicit connections with their students about the technology that they were using or that they were building. None of the teachers explained to their students what technology is and how it relates to their final products.

Although technology appeared in all the STEM integration lessons, teachers did not explicitly make connections to their students about the technology that they were using or building. Therefore students might not be able to connect the concept of technology in their STEM integration lessons. In addition, students might not perceive how technology has influence on humans' lives through interactions among science, technology, engineering, and mathematics.

What Are Secondary Science Teachers' Overall Perceptions of STEM Integration?

Teachers considered the technology in a STEM integration lesson to be integrating computers and other digital devices, or the products that students created for their STEM integration projects, or both. When teachers talked about integrating technology, most of the teachers (Kathy, Reese and Sid) automatically mentioned computers or other digital devices, such as a gene gun or motion detectors. In other words," high-tech" technology was the technology that they considered for their STEM lessons. Kathy said, "[In the Robotics unit], the technology part was the programming on the computers and students' presentation by using PowerPoint...Now our school is getting more technology. It is easy for us to start incorporating laptops and using online resources." Although Carolyn suggested that she used a lot of "traditional" technology, such as spring scales, in her Candy Bag activity, unconsciously, when she talked about technology, she particularly implied computers. She said, "Our school did not have enough high-technology resources, such as computers, for me to use," and "If we have enough technology resources, like computers, I want to use them… However, it would not make any sense if we asked our school to spend a million dollars to buy high-tech gadgets for sixth graders." Reese constantly talked about computers as a technology that she used in her Genetic Engineering project. She talked about how her students used computers and online resources to complete their research and presentations. Sid stated that he would like to incorporate more technology by using motion detectors in his Egg Drop project.

On the other hand, Sid also believed another piece of technology in his Egg Drop project was the devices that he wanted his students to create. This perception of technology could also be found in Lisa's case. Lisa said, "As for technology, when I asked [students] to create their GMOs, the GMO that they came up with is the technology."

What Is The Connection between Secondary Science Teachers' Perceptions and Understanding of STEM Integration with Their Classroom Practices?

When talking about integrating technology, all of the teachers either referred to technology as computer or digital devices, or the product that students created for their STEM integration lessons, or both. For the teachers who restricted technology as computers or digital devices, they believed it was difficult to integrate technology due to limited resources. For example, Kathy and Carolyn specifically mentioned that they did not have enough resources (computers) for them to use and that changed how they planned their STEM integration lessons. On the other hand, the teachers who considered technology as the product that students created in their STEM integration lessons had a broader view of technology than teachers who just considered technology as computers or digital devices. One interesting thing to note is that all the STEM integration lessons have a final product. Teachers could/should have held this "technology as the final product that students created" view when expressing how they integrate technology in their STEM integration lessons. However, only Lisa and Sid perceived this as integrating technology in their STEM integration lessons. Integrating technology as the final product is a misalignment of perceptions and practices of STEM integration.

Perceived Constraints to STEM Integration

This theme discusses the issues or difficulties that teachers encountered while they implemented their STEM integration lessons. This theme was not presented by following the pattern of the other themes, because this theme particularly explored the struggles or difficulties after the teachers implemented their STEM integration lessons. This theme highly related to teachers' perceptions, but could hardly be observed in their

STEM integration practices. This theme represented the reflections from all the teachers after they implemented their STEM integration lessons. It is important to note that some of the issues or difficulties are highly associated with other themes that have been presented in this chapter.

There were four issues or difficulties that teachers talked about after implementing their STEM integration lessons that specifically relate to STEM integration. First, most of the teachers (Kathy, Lisa, Carolyn and Reese) believed that their students' abilities in the STEM subjects had a great influence on how they could design their STEM integration lessons. The middle school teachers (Kathy, Lisa and Carolyn) were particularly concerned about how much scaffolding their students needed in order to understand and complete their STEM integration projects. Second, all of the teachers believed that some science units/subjects, such as energy, force, ecology, or biotechnology were easier topics with which to use STEM integration. However, some teachers, such as Kathy and Reese, believed some science units/subjects, such as matter or chemistry, were not. Third, most of the teachers (Kathy, Lisa, and Carolyn) were concerned that the fun part overshadowed the work that students needed to complete in a STEM integration lesson. Finally, time and resources were huge issues that influenced how teachers designed their STEM integration lessons.

Students' Abilities

The teachers were concerned about how their students' abilities, such as mathematics and technology skills, influenced their learning in a STEM integration lesson. This concern also influenced how they designed their STEM integration lesson. For example, Kathy said, "If I want [students] to use computers to do research, I need to spend a lot of time to explain it. Sometimes I just don't have the time to do that." Lisa said, "If I just said, 'OK, Google genetic engineering'… I don't know if that will be really useful... Most of [the students] are not super fast readers…So I told them which websites they should go to," and "I think [STEM integration] makes [students] use mathematics skills that are really challenging for them. I think some of the kids just don't have the mathematics background." Carolyn stated, "We have students where it seems like really basic math, and yet it is something that they need constant reinforcement on…I guess that really is where math ends up in my class," and "So how much we can use [computers] in a science classroom is really dependent on how we can meet [students] where they are." This concern actually relates to the teachers wanting to use their STEM integration lessons to help students to connect their existing STEM knowledge. This concern can link back to a culminating type of STEM integration project, because the teachers wanted to their students to use their existing STEM knowledge to create their STEM projects.

The middle school teachers particularly believed that their students were still in a process of learning how to problem solve. They also worried about how much direction they needed to give to their students for them to complete their STEM projects. Kathy said, "[Students'] brains still try to connect all the information that they have learned to what they want and what they do. You have to explicitly teach all the content knowledge that they need." Lisa stated, "[STEM integration] is a little chaotic because [students] are not exactly sure what stage they are supposed to be on…I need to do a little more hand holding as I introduce an activity like this." Carolyn pointed out, "[Students] needed a lot of direction. I felt like what you can do for STEM integration partly depends on where your students are," and "I am a middle school science teacher... My students needed a lot of guidance to do the [Candy Bag] project."

Another issue related to students' abilities was that some teachers (Lisa and Reese) believed that some students needed more time to complete their STEM project than other students. This made it more difficult for teachers to plan their schedules. Lisa said, "Keeping the project moving along at a pace that makes sense without having too many kids finish early and have nothing to do is my challenge." Reese said, "[Students] are working on a different time line. It is hard for me to tell them, 'Hurry up, you are so behind.' Some kids just don't use their time wisely. Some kids just don't know what to do."

STEM Integration and Content Must Be Compatible

The teachers believed some science units were more conducive for incorporating STEM integration. For example, Kathy suggested, "I don't think about STEM integration the whole time. It is easier to do STEM integration in some units, such as force, motion, and energy than some units, like matter." Lisa compared her Genetic Engineering activity with her Zoo project activity and said, "With genetic engineering, it is part of a big genetic unit…Whereas the zoo project, I feel I can touch on a lot of aspects of ecology when we make a zoo exhibit…I can use that project through the entire unit." Carolyn said, "Matter is hard... I don't know if I would be able to use STEM integration to teach [matter]." To some teachers, implementing STEM integration is a very selective choice depending on how they could make STEM integration and the science content compatible.

One of the possible explanations for this struggle was that the teachers picked a content area or topic that allowed them to address engineering design. Science and engineering are the two most important components that they need to integrate. If a science unit, such as matter, does not easily integrate engineering design the teachers considered it was hard to do as STEM integration. Again, their perceptions and classroom practices of STEM integration were highly affected by the Nature of Science and Engineering standards.

Not only science content, but also different science subjects and even different disciplines would have different difficulties in implementing STEM integration. For example, Kathy used to teach mathematics. She considered that it would be easier to use STEM integration in a science class than in a math class. As for Reese, she encountered different issues when she tried to implement STEM integration in different subjects, such as biotechnology and chemistry. She said, "I think in biotechnology, it is hard to do math and it is hard to add engineering into chemistry," and "I feel I don't have a good theme for my chemistry class to connect everything. To me, it is hard to do STEM integration in chemistry."

Fun vs. Learning

Overall, the STEM integration classes tended to be very chaotic. Students talked loudly to their partners about their design, walked around in a classroom to test their product, or just goofed around and did not do anything that they were supposed to be doing.

One of the conflicting issues in the STEM integration lessons was the "fun factor". Kathy, Lisa, and Carolyn pointed out that STEM integration really engaged their students to do their projects. However the teachers were also concerned that the fun part overshadowed the learning that students needed to complete a STEM integration lesson. Kathy said, “[Students] love [a STEM integration project]… For some reason, like some of the kids, even though they were totally motivated and engaged, they didn’t do that part of their package for the day,” and “If they did not do [reflections and notes], I would not know what they had learned from that day. I felt they just put their robots together without thinking it through.” Lisa believed, “[Students] don’t want to go slowly, carefully, working through their ideas. They don’t want to talk about the strengths and weaknesses of their products…They like the hands-on part, such as drawing their posters and building their genetically modified organism.” Carolyn stated, “The biggest [challenge] is getting [students] to do the ‘not fun part,’ such as the documentation and the reflection. The measurement part is not fun to them. So, they do a very sloppy job on that.”

Time and Resources

Time was a big issue for the teachers in designing and implementing their STEM integration lessons. Lisa believed that she needed more time to do STEM integration than her regular science class. She said, “To me, time is always the challenge. [Students] may need a longer amount of time than I want them to take. It takes longer to do STEM integration. You just have to plan for that.” Kathy, Carolyn, and Sid particularly pointed out that when designing their STEM integration lessons, they really needed to consider how much time they could use for the lesson. Carolyn and Sid suggested if they had more time to do their STEM integration lessons, they would integrate more STEM subjects or make their lesson more comprehensive. Carolyn said, “We don’t have 3 months to do a project. I think the time limitation is just a huge piece. We need a project where it is reasonable for [students] to accomplish something in, frankly, very little time," and "If we could have an hour and a half, or 2 hours for a class to do a project, we might be able to think bigger." Sid said, "Time is a huge factor. I mean we only have 3 days. I definitely can add more math pieces in [the Egg Drop project], but that also requires more time to do the project," and "Can we use the motion detectors in [the Egg Drop project]? Absolutely! But, kids struggle with the math. It is like we really need all of those 3 days to build, then drop. Time is probably the biggest issue."

Kathy demonstrated a different point of view on the time issue. She was given the Robotics unit to teach throughout the entire quarter. She believed the unit was too long and she did not like solely teaching engineering and technology for such a long time. She said, "The [Robotics] unit was too long. That is what [the school] want [s]. I really think if I do it again, instead of a whole quarter, I want to shorten it to maybe a month long lesson."

The teachers also talked about how other resources, such as technology, materials, and spaces might change how they implement their STEM lessons. Kathy and Carolyn articulated the issues related to technology. Kathy said, "I think the technology piece is the hardest part for me to do in STEM integration, mainly because we just don't have a lot of stuff in our school." Carolyn said, "Our school did not have enough high-technology resources, such as computers, for me to use." Sid particularly mentioned that materials and space influenced what he wanted to do for his STEM integration lessons. Sid was going to do a Cardboard Chair project with his students; however he could not find enough materials and enough space to store the materials. Therefore instead of doing the Cardboard Chair project, he changed his plan to the Egg Drop project. He said, "I was actually going to do something different; building cardboard chairs. I just couldn't do it. If I am going to do that, I will need a garage to store all the cardboard," and "Materials are always an issue. I need materials that are easy to access and fit well."

Summary

Problem solving was one of the major concepts that emerged from all the STEM integration lessons. When implementing their STEM integration lessons, all of the teachers had an open-ended engineering problem/challenge that was simulating a real-life situation. All the teachers introduced the open-ended engineering problem/challenge at the beginning of their STEM integration lessons. The open-ended engineering problem/challenge was seen as the first step of doing the engineering design process. In fact, engineering design was another critical element that could be observed in all the STEM integration lessons. Some of the teachers, such as Kathy and Carolyn, particularly designed their STEM integration lessons as engineering design projects. They explicitly asked students to use the engineering design process to design their final products step by step. Although Reese and Sid did not explicitly help students make a connection with engineering design, the elements of engineering design, such as conducting research, mapping out budget sheets, and/or drawing a prototype of a design, could be observed in their STEM integration lessons. All the STEM integration lessons also had a final product that required the students to do some hands-on work. For example, students needed to design a candy bag for Carolyn's STEM integration lesson, and Lisa asked her students to create a poster or a craft GMO that could be presented in front of the class.

All the teachers wanted their students to apply their existing knowledge to the problem solving in their STEM integration lessons. For example, Carolyn asked her students to think about what they had learned before measuring the volume and mass of their candy bags. Sid also asked his students to think about momentum before they designed their egg protection devices. In all the STEM integration lessons, the teachers' roles were more like facilitators rather than instructors. They told students to use their creativity and imagination to come up with a solution or answer for the problem. They encouraged students to brainstorm and try different ideas to solve the problem. Students were very excited and not afraid to try their ideas.

Two major ways to implement STEM integration in a science classroom emerged from the data. In this study, STEM integration was used as 1) a culminating project (Lisa, Reese and Sid) or 2) as an engineering project (Kathy and Carolyn). The purpose of using STEM integration as a culminating project was to apply and/or reinforce the science concepts that students had learned. As for using STEM integration as an engineering project, the teachers' primary goal was to introduce students to engineering design.

The teachers believed that independent thinking is a very important quality for real world scientists and engines when they do their jobs. Teachers believed that a STEM integration lesson could help students develop their ability to think independently while working on the project as a real world scientist and engineer. Because students needed to generate their own ideas to solve a problem/challenge, all the teachers believed that it was very important that students first acquired content knowledge, such as science, mathematics, and/or technology skills, before they could solve a problem. In fact, all the teachers agreed that STEM integration is a strategy that can help their students apply what they have learned in a new situation.

The primary focus on science and engineering in a STEM integration lesson is likely due to the Nature of Science and Engineering standards. The teachers felt that they have an obligation to address the Nature of Science and Engineering standards because they are science teachers. The teachers considered engineering as the most important aspect of STEM integration. They started to design their STEM integration lessons by finding a science content area that facilitated the integration of engineering into that content area. Math and technology were secondary considerations in planning their STEM integration lessons. In general, the teachers treated mathematics and technology as tools that they could use to help solve a problem within their STEM integration lessons. Interestingly, the Nature of Science and Engineering standards describe mathematics and technology as tools to help students learn science and engineering concepts, possibly reinforcing the teachers' perceptions and their implementation of STEM integration.

Four issues or difficulties emerged when the teachers implemented their STEM integration lessons in their science classrooms. First, students' abilities in the STEM subjects had a great influence on how teachers designed their STEM integration lessons. This concern highly related to the fact that the teachers wanted to use their STEM integration lessons to help students apply their existing STEM knowledge to problem solving and engineering design. Second, the teachers believed that STEM integration may only be implemented in some science units/subjects, such as force and energy, because these units/subjects are easier to integrate than other STEM subjects. This concern derives from the teachers' perception that engineering design is the key element in their STEM integration lessons. As stated above, the teachers started to design their STEM integration lessons by finding a science content area that facilitated the integration of engineering. If a science content area, such as matter, does not have distinct connections with engineering design, then they considered it to be a difficult topic for STEM integration. Third, it is difficult for teachers to balance the fun and learning in a STEM integration lesson. Finally, limited time and resources can influence how teachers design their STEM integration lessons.

Overall, the teachers' practices and perceptions of STEM integration focused on problem solving, application, and engineering design. They believed these three features of STEM integration helped their students to apply their existing STEM knowledge and also learn life skills, such as learning from mistakes and failures. By solving an engineering open-ended problem that simulated what real engineers do for their jobs, students used their creativity and imagination to generate ideas, and did hands-on applications to express their ideas, both considered by the teachers to be the essence of STEM integration.

Chapter 6 will continue to use these themes presented in this chapter to build the secondary science teachers' STEM integration model and align the model with literature studies.

CHAPTER 6

Discussion, Implications, and Future Research

Discussion

This chapter intends to generate a meaningful discussion about how the secondary science teachers' perceptions and classroom practices of STEM integration relate to previous research studies, and about the implications for educators and researchers working to improve STEM integration in K–12 settings. By exploring the five teachers' perceptions and classroom practices of STEM integration, this chapter aims to construct a STEM integration model based on the teachers' perceptions and practices and to align the model with existing literature. It is important to note that the purpose of this study and the secondary science teachers' STEM integration models are not for the researcher to determine the quality of the STEM integration lessons, but rather to provide a better understanding of teachers' current knowledge, perceptions, and classroom practices about STEM integration. The secondary science teachers' STEM integration model developed here acts as a reference that can put forward useful information to help policymakers, educators, and researchers make informed decisions about the direction and necessity of professional development and educational program design for STEM education.

The Secondary Science Teachers' STEM Integration Model

What is STEM integration? The results from this study suggest that the participants believed that STEM integration cannot be defined by how many STEM disciplines should be integrated in a lesson. Instead, they believed that STEM integration is where students use engineering design and can apply their science and/or mathematics knowledge to test their own ideas and to generate different solutions to solve a problem in a new situation. The teachers view the integration of science and engineering as the most important aspects of STEM integration. Mathematics and technology are secondary considerations that they consider as tools to solve a problem/challenge for science or engineering. The primary drivers for the teachers in this study to make decisions about STEM integration are represented in five of the themes presented in chapter 5, 1) the focus of STEM integration is problem solving, 2) the focus of STEM integration is application, 3) the focus of STEM integration is engineering design, 4) the focus of STEM integration is life skills, and 5) connections to science content (under the perceived constraints to STEM integration theme). Figure 3 provides a model of how the teachers thought about STEM integration. All five of the themes can play an important role in the decision points that have an influence on how the teachers design and implement their STEM integration lessons.

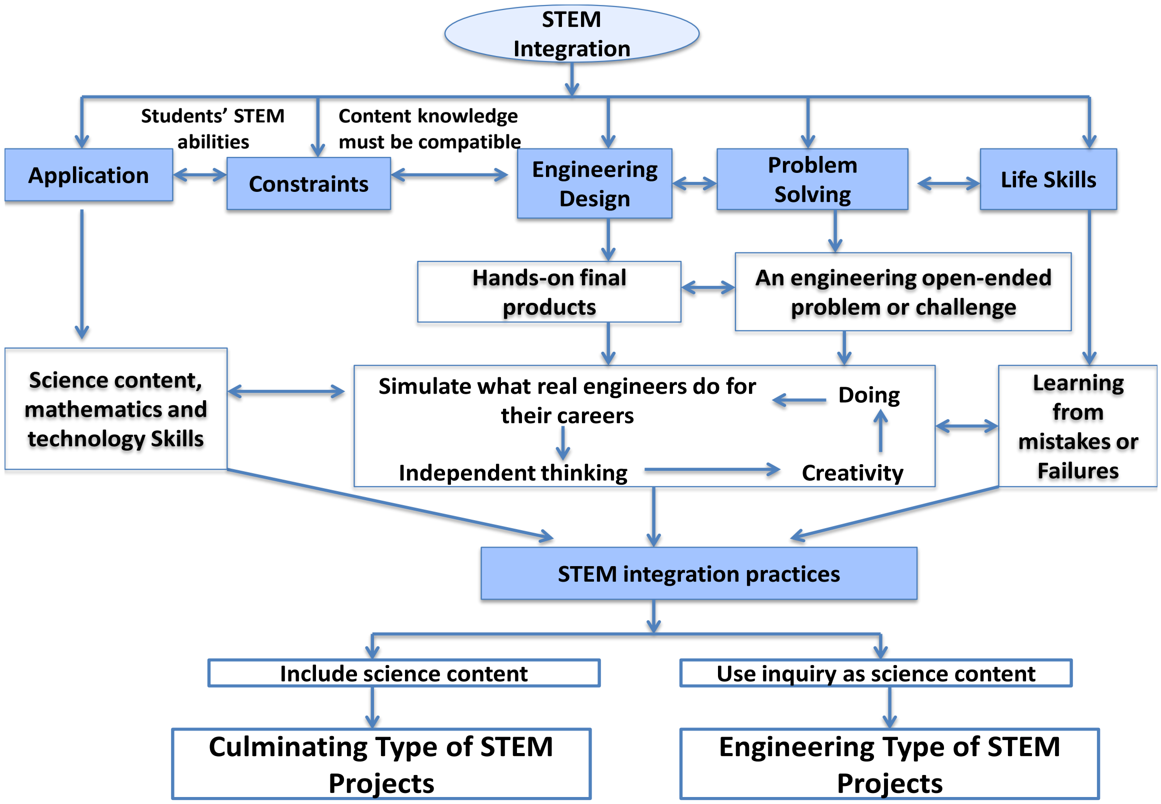

Figure 3. The secondary science teachers' STEM Integration Model.

The central part of the model shows that engineering design, problem solving, application, and life skills are related to teachers' thinking about STEM integration. Most of the teachers believed that students' STEM abilities have influence on how the teachers could design their STEM integration lessons. For example, if their students do not have knowledge of how to use computer software, the teachers would not consider using that software in their STEM integration lessons. This constraint particularly relates to one of the main concepts; application. In addition, if a science unit, such as energy, is easy to integrate with engineering design, the teachers would consider teaching the unit by using STEM integration. However, if the unit is not easy to integrate with engineering concepts, such as matter, the teachers would not consider using STEM integration to teach that unit. This perception highly associates with the concept of engineering design.

An open-ended engineering problem or challenge and a final product are the two necessary features for STEM integration in the teachers' model. In all of the STEM integration lessons, the teachers started their STEM integration lessons by giving students an open-ended engineering problem or challenge. In addition, at the end of their STEM integration lessons, a final product, such as a robot, an egg protection device, a presentation, or a poster, was one of the major criteria that students are graded on. Teachers used the design of these products to incorporate the critical model components of engineering design and problem solving into their STEM integration lessons.

Science content, mathematics, and technology skills appear to be the most important elements that the teachers wanted their students to apply when using STEM integration lessons. They wanted their STEM integration lessons to reinforce science content for their students and to encourage the students to use their existing mathematics and technology skills by solving an engineering design problem.

Another important driver of the teachers' STEM integration model involves the learning of life skills. These life skills are related to learning from failure, developing creativity, and using independent thinking. All teachers indicated life skill development as an important component and benefit to STEM integration. Life skills were directly related to the teachers' desire for their students to try their own ideas or solutions to solve the engineering problem or challenge. Some of the teachers, such as Carolyn, Reese, and Sid, believed that students learn from their mistakes or failures to improve their final products. When doing STEM integration, students realized that each experienced mistake or failure is invaluable because it can guide them in the right direction. Some of the teachers, such as Kathy and Lisa, believed that not giving the students the correct solution might make their students feel frustrated. But by trying their own ideas and solutions, students would learn to deal with their frustration in order to complete their projects.

Most of the teachers stated that they wanted their STEM integration lessons to simulate the work of a real world scientist or engineer. They believed scientists and engineers always have a question or an engineering problem or challenge in their minds that they want to solve. They believed that in a real world situation, the question or the problem does not have one correct answer. Scientists and engineers need to use their creativity to solve a question or an engineering problem. The teachers also believed that students need to physically do hands-on attempts to solve a problem by creating a final product. Because all the teachers provided students with engineering problems or challenges rather than scientifically oriented questions, it would be more appropriate to say that all the teachers actually simulated what engineers do for their work rather than what scientists do for their work in their STEM integration lessons. The teachers began their STEM integration lessons with an open-ended engineering problem or challenge. Independent thinking, creativity, and hands-on work to create a final product are important elements that they have to ask their students to do in their STEM integration lessons.

Specific patterns in the teachers' thinking about these five primary themes lead to two very different models for STEM integration: culminating projects or engineering projects. This led to two related themes: application and connection of specific science content, or using inquiry as science content. Kathy and Carolyn used engineering design as the main focus in their STEM integration lessons. They wanted their students to use the engineering design process step by step to solve a problem—designing an assistive robotic device (Kathy) and designing a candy bag (Carolyn). The main learning goal for their STEM integration lessons was for students to learn about and practice the engineering design process. The science content that these two teachers set out for students to apply in their engineering design lesson was called "science as inquiry". Given the teachers' perception of inquiry as process skills, the integration of process skills into the engineering design challenge resulted in a lesson that was simply an engineering design project without any implicit or explicit connection to science content.

On the other hand, Reese, Lisa, and Sid wanted to give students a challenge that would allow them to apply previously learned science knowledge to their engineering design challenge. These teachers wanted their students to apply specific science content, such as momentum or genetics to solve an engineering problem/challenge. All of these teachers integrated science and engineering in their STEM lessons and in some cases also allowed students to apply mathematics and technology skills in culminating projects.

This section described how the results from this study informed the model of teachers' STEM integration. The next section will tie the model to the literature on curriculum integration.

Alignment of the Secondary Science Teachers' STEM Integration Model with Existing Literature on Curriculum Integration

In Chapter 2 important aspects of curriculum integration from the literature were presented and discussed (for example, see Table 3). It is critical to link the secondary science teachers' perceptions and classroom practices of STEM integration back to different types of curriculum integration to generate discussion about how the secondary science teachers' STEM integration model relates to existing literature. Alignment of the secondary science teachers' STEM integration model with existing literature on curriculum can help educators, researchers, and policymakers to move forward toward a theoretical framework. In the following section, the alignment of teachers' ideas about STEM integration are discussed in terms of the following models of curriculum integration from the literature: 1) a theme, such as a problem or an issue, to connect disciplines (Davison et al., 1995; Huntley, 1998) and a real-life problem/issues that address personal interests (Drake, 1991, 1998; Fogarty, 1991), 2) within a single discipline or cross-discipline integration (Davison et al., 1995; Drake, 1991, 1998; Fogarty, 1991; Huntley, 1998), 3) content/concept specific and process/skills specific integration (Berlin and White, 1995; Davison et al., 1995; Fogarty, 1991), and 4) teaching strategies that help students to learn (Berlin and White, 1995; Davison et al., 1995).

First, all the STEM integration lessons started with an open-ended engineering problem or challenge. The teachers believed that it was important to provide an authentic learning experience to students by simulating what an engineer does for his or her job. The teachers also associated STEM integration with real world problems. For example, Kathy wanted her students to design an assistive device that could help people with special needs. Sid told his students to think about a car crash when they tried to design their egg protection devices. The secondary science teachers' STEM integration model suggests that STEM integration provides students more meaningful learning experiences by using a theme to connect STEM knowledge with personal and real world experience, which touched upon the concept of the webbed model (Fogarty, 1991), thematic integration approach (Davison et al., 1995) and meaningful learning (Beane, 1991, 1995; Burrows et al., 1989; Capraro & Slough, 2008; Childress, 1996; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). In order to provide students with a learning experience that is more meaningful to them, the webbed model, thematic integration approach, and meaningful learning all suggest that curriculum integration needs a theme to connect different disciplines. The teachers' intentions to provide a personal and real world connection for their students are clear; however, this study does not include data to make a judgment about students' perceptions and interest related to the themes chosen by the teachers.

Huntley (1998) proposed a theoretical framework for science and mathematics integration by using the following three concepts: *intradisciplinary*, *interdisciplinary* and *integrated*. An intradisciplinary curriculum focuses on a single discipline. Although all the teachers stated that they integrated science and engineering into their STEM integration lessons, Kathy also reflected that her Robotics unit was "a stand-alone engineering type of lesson." In her Robotics unit, Kathy focused on nothing else but engineering. Therefore the Robotics unit is categorized as an intradisciplinary curriculum, in which instruction occurred within a single discipline. Huntley (1998) believed that the idea of implicitly or explicitly integrating disciplines is an important consideration in distinguishing between interdisciplinary and integrated curriculum. She suggested that in an integrated curriculum, teachers needed to explicitly make connections between or among disciplines by giving equal attention to two (or more) disciplines. Lisa and Carolyn, the middle school teachers, explicitly taught about engineering in their STEM integration lesson by teaching students the engineering design process using a step-by-step approach. Lisa not only explicitly taught engineering design step by step, she also explicitly taught science content, such as the difference between selective breeding and genetically modified organisms, in her Genetic Engineering activity. As for Carolyn, besides implicitly using engineering design, she also explicitly told her students to use their mathematics skills to measure the volume of their candy bags. Sid and Reese, although they included engineering design in their STEM integration lessons, did not purposefully and explicitly make a connection to the role that engineering played in their STEM integration lessons. They implemented engineering design in their STEM integration lesson without discussing the design process with their students. As a result, Lisa and Carolyn's STEM lessons fell into integrated curriculum, but Reese and Sid's STEM lessons fit into interdisciplinary curriculum.

A major focus for all the STEM integration lessons in this study was problem solving. Most of the teachers stated their main purpose in STEM integration to be facilitating students' ability to apply the science and mathematics content they had learned earlier in the unit or class. Therefore most of the teachers focused more on "process practice," such as emphasizing observing, inferring, reasoning, and problem solving rather than "content delivery," such as what velocity and speed are (Berlin and White, 1995; Davison et al., 1995), when they implemented their STEM integration lessons. For example, Kathy, Lisa, and Carolyn used engineering design as a process to help students solve a problem. They wanted their students to use the engineering design process to solve the engineering problem. Although Reese and Sid did not explicitly teach engineering design step by step, they emphasized independent thinking skills in their STEM integration lessons. The teachers gave the engineering problem or challenge to their students and the students needed to come up with the best answer or solution for the problem or challenge. They valued the "thinking process" that students tried when solving the problem or challenge. Problem solving is the major focus in their STEM integration lessons. Therefore all of the five STEM integration lessons can be categorized as process/skill specific.

On the other hand, Lisa, Reese, and Sid had specific science content that they wanted their students to take into account when designing their final product. For example, Lisa placed her Genetic Engineering activity at the end of her gene unit. Her intention was to help students to connect what they had learned about genes with genetic engineering. Lisa talked about the difference between selective breeding and genetically modified organisms in her class. Sid implemented his Egg Drop project at the end of his momentum class and before he introduced his energy unit. Students had learned what momentum is before he implemented his Egg Drop project. He wanted to reinforce the concept of momentum by unequivocally telling his students to think about momentum when they designed their egg protection devices. Therefore, Lisa, Reese, and Sid's STEM integration lessons also could be categorized as both process/skill and content/concept specific curriculum integration (Berlin and White, 1995; Davison et al., 1995).

The teachers' decision to follow a content/concept specific or process/skills specific integration model is the decisive factor leading to different STEM integration models, regardless of the nature of the STEM integration lesson as intradisciplinary (Kathy), interdisciplinary (Reese and Sid), or integrated (Lisa and Carolyn) curriculum (Huntley, 1998). Lisa, Reese, and Sid had specific content that they wanted students to take into consideration when they designed their final projects. These teachers also placed their STEM integration lessons at the end of a class, a unit, or a course. They intended to use their STEM integration lessons to help their students apply the science content that they had previously learned. Therefore Lisa, Reese, and Sid's STEM lessons fell into culminating projects. As for Kathy and Carolyn, they focused on the engineering design process without purposely embedding any specific content in their STEM integration lessons. Although Carolyn had integrated mathematics, she had students follow a mathematical procedure rather than teach them a mathematical concept in her Candy Bag activity. For these reasons, Kathy's and Carolyn's STEM integration lessons fit into an engineering project, which focused more on process and procedure. To conclude, it is important to note that when the teachers were asked to define STEM integration, they believed that STEM integration should not be defined by how many STEM disciplines should be integrated in a lesson. This perception corresponds to the secondary science teachers' STEM integration model and past literature studies. It is not how many disciplines are used or what type of discipline integration is employed (such as within a single discipline integration or cross-discipline integration) that determines the type of STEM integration projects.

In conclusion, as Drake (1998) suggested, "One position is not superior to another: rather, different approaches are more appropriate than others according to the context in which they are used (p. 19)." The purpose of this study is not for the researcher to decide which STEM integration lessons represent the best model. However, Figure 3 does provide some useful information to help educators and other researchers to be aware of what elements are insufficient or missing in the secondary science teachers' perceptions and classroom practices of STEM integration. For example, problem solving is important in STEM integration. In addition, Figure 3 also can provide useful information about what type of STEM integration model a teacher may choose to use based on his or her needs.

Implications

The participants in this study asserted that the Nature of Science and Engineering standards are one of the biggest forces pushing them to focus on science and engineering. The findings also suggested when implementing STEM integration, the teachers believed that they have to integrate science and engineering in their STEM integration lessons. As for mathematics and technology, they considered these two disciplines as an afterthought in their STEM integration lessons. Even though the teachers were trying to focus their STEM integration lessons on science and engineering, the results suggested that the secondary science teachers might misuse some science concepts, such as inquiry, because they did not distinguish science and engineering in their STEM integration lessons. For policymakers, these are the points that need to be taken into consideration. Policymakers need to understand how teachers interpret legislative documents, such as the Nature of Science and Engineering standards, and how they integrate these documents into their teaching. For example, the teachers suggested that they follow the Nature of Science and Engineering standards as guidelines to design their STEM integration lessons; the content and specific wording of standards have a strong influence on classroom practices. The question that policymakers need to ask is: Is the focus on science and engineering what we want for STEM education in K–12 settings?

In addition, the teachers' STEM integration perceptions and classroom practices focused on certain qualities of STEM integration, such as problem solving, application, and engineering design. However, when teachers focus on problem solving, application, and engineering design in their STEM integration lessons, the lessons actually become more engineering focused rather than including a strong science focus. If we want STEM integration to mean more than problem solving, application, and engineering design in K–12 education, there is no doubt that teachers will need a lot of support to help them with more ideas for implementing STEM integration while maintaining a focus on learning science content.

The desire to implement STEM integration in science classrooms is not enough to bring about quality STEM education in K–12 schools. To improve K–12 STEM education, a more comprehensive view of STEM integration and models for quality STEM integration are critical. Policymakers must empower teachers with strategies on how to implement STEM integration. For example, developing good quality STEM integration lessons is important. A good quality STEM integration lesson not only needs to address the subject that teachers already teach but also should relate to other STEM subjects' standards. This can help teachers teach STEM integration in a more effective way and make them more willing to implement STEM integration in their classrooms. In addition, professional development programs and support from school administration are critical. STEM professional development programs can place more focus on helping teachers develop a more sophisticated understanding of and comprehensive strategies for classroom practices of STEM integration. For example, in this study, the teachers have demonstrated that the goals of their STEM integration lessons were to increase problem-solving capabilities, enhance creative thinking skills, and engage students in learning science. STEM professionals should develop programs that provide more assistance to teachers in how to incorporate science and mathematics content into their STEM integration lessons.

Expectations surrounding the integration of STEM in K–12 education need to be more explicitly defined. For the researchers, the first step is to create a theoretical STEM integration framework that describes how STEM integration should be put into practice in K–12 classrooms. The secondary science teachers' STEM integration model suggests that the teachers focus on real world engineering problem, application of science, problem solving, and independent thinking. However, the terms "problem solving" and "independent thinking" were used broadly by the teachers. The real role of problem solving and independent thinking in their STEM integration lessons is not clear and they had a hard time explaining what problem solving and independent thinking consisted of when asked during interviews. Since the teachers were very ambiguous about these key elements in their perceptions and classroom practices of STEM integration, it is very important for researchers to help teachers develop a clear view about the key elements in STEM integration.

Recommendations for Future Research

The focus of this study was to explore secondary science teachers' STEM integration perceptions and classroom practices. A necessary next step would be to conduct a study to look at student learning when implementing a STEM integration lesson in a science classroom. A study that addresses student learning can provide a more comprehensive view of how STEM integration is able to help or not help students' learning in STEM disciplines. In addition to looking at STEM disciplines, since problem solving is one of the major focuses in STEM integration, future research should also explore students' problem solving skills and abilities when implementing a STEM integration lesson in a science classroom.

Another central and important issue for further study is to examine the STEM legislation and expectations for the integration of STEM disciplines in K–12 setting from a national and statewide policy level. This could help to create a framework for STEM integration in K–12 education that can guide educators, researchers, and policymakers to examine and evaluate the outcomes of STEM integration. This is also a very important step in determining the role of where STEM integration should fit in K–12 STEM education.

Finally, by recruiting five secondary science teachers, this study constructs the secondary science teachers' STEM integration model. However, the number of participants in this study might be a limitation. To test the secondary science teachers' STEM integration model, a study that has more participants is important to verify if the model can represent overall secondary science teachers' perceptions and classroom practices of STEM integration. In addition, this study lacks information about elementary level teachers' perceptions and classroom practices of STEM integration. A study that addresses elementary teachers' perceptions and classroom practices of STEM integration may provide a different viewpoint of how STEM integration should be implemented in K–12 education.

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APPENDIX A

Pre-Interview Protocol

Name		Date	
Degree(s)/Licensure		Teaching Specialty	
STEM experience		Interviewed by	

Q1.A	Tell me about the nature of science	
	Q1 B	Tell me about the nature of mathematics
	Q1 C	Tell me about the nature of engineering
	Q1	Tell me about the nature of technology
Q2	Please define STEM integration? Does that relate to your teaching and your students' learning? How? (Can you give me an example?)	
	Q2 a	What are the strengths and weakness of using STEM integration in your teaching?
	Q2 c	If giving a choice, will you use STEM integration in your teaching? Why or why not?
	Q3 d	Do you believe that STEM integration helps or could help your students learn science? In what way?
Q3	Have you used STEM integration in your teaching before?	

Yes	No
How have you integrated engineering, technology, science, and mathematic into your teaching? How do you design your STEM activity by using each discipline?	How would you design your STEM integration activity by using each discipline?
Could you give me one of the best STEM integration activities example that you have done?	Could you give me an example how you will use STEM integration activities?

	Q3a	Which part of your STEM activity that you particularly want your students to understand or to comprehend?
	Q3 b	What are some difficulties?
	Q3 c	What are some benefits?

APPENDIX B

The Robotics Unit

SIOP Lesson Plan [redacted]

Date: 01/31 & /2/01 **Subject/Grade:** 6th Grade Science

Unit: Engineering Robotics **Standard(s):**

Content Objective(s): Students will begin to understand the Engineering Design Process.

Language Objective(s): Students will be able to discuss how to use different parts of the Robotics Kits.

Key Vocabulary	**Materials**
Engineering Design Process	Seating Chart, Engineering Design Process Sheets, Scissors, Robotics Kits

SIOP FEATURES

Preparation	Scaffolding	Group Options
Adaptation of content	**Modeling**	**Whole class**
Links to background	Guided practice	Small groups
Links to past learning	Independent practice	**Partners**
Strategies incorporated	**Comprehensible input**	**Independent**

Integration of Processes	Application	Assessment
Reading	**Hands-on**	Individual
Writing	Meaningful	Group
Speaking	**Linked to objectives**	**Written**
Listening	**Promotes engagement**	**Oral**

Lesson Sequence:

1) **Warm Up:** Find your seats: If you are a boy, sit at an odd numbered table, if you are a girl, sit at an even numbered table.
2) 4 Corners Game if time.
3) New Seating Chart
4) Classroom Rules
5) Notebook Check and set up
6) Robotics Rules
7) Engineering Design Process- Vocabulary, Example and Discussion
8) Explore Robotics Kits
9) Discuss how different parts can be used. Write up a conclusion.

Figure B-1. The robotics unit: Lesson plan (1).

SIOP Lesson Plan [redacted]

Date: 02/02 & /2/03 **Subject/Grade**: 6th Grade Science

Unit: Engineering Robotics **Standard(s):**

Content Objective(s): Students will understand what an assistive device is.

Language Objective(s): Students will be able to talk with team members on how to complete the challenge.

Key Vocabulary	**Materials**
Assistive Device	Various Readings, Wheelchair challenge page, Robotics Kits

SIOP FEATURES

Preparation	Scaffolding	Group Options
Adaptation of content	**Modeling**	**Whole class**
Links to background	Guided practice	**Small groups**
Links to past learning	Independent practice	**Partners**
Strategies incorporated	**Comprehensible input**	**Independent**

Integration of Processes	Application	Assessment
Reading	**Hands-on**	**Individual**
Writing	**Meaningful**	**Group**
Speaking	**Linked to objectives**	**Written**
Listening	**Promotes engagement**	**Oral**

Lesson Sequence:

1) **Warm Up:** What is one device that helps you every day?
2) Talk about **assistive devices**. Write vocabulary in note books.
3) Have students chose one reading and work on it individually.
4) Discuss the different readings as a whole class.
5) Wheelchair challenge.
6) Work time for wheel chair challenge.
7) Test wheelchairs if time.
8) Make sure students record notes and diagrams so they can reconstruct chairs next time if needed.
9) Conclusion: talk about what was the most successful part of the wheelchair construction.

Figure B-2. The robotics unit: Lesson plan (2).

SIOP Lesson Plan [redacted]

Date: 02/04 & 02/07 **Subject/Grade:** 6th Grade Science

Unit: Engineering Robotics **Standard(s):**

Content Objective(s): Students will understand what a constraint is.

Language Objective(s): Students will be able to talk with team members on how to complete the challenge.

Key Vocabulary	**Materials**
Constraint	Wheelchair challenge page, Robotics Kits

SIOP FEATURES

Preparation	Scaffolding	Group Options
Adaptation of content	**Modeling**	**Whole class**
Links to background	Guided practice	**Small groups**
Links to past learning	Independent practice	**Partners**
Strategies incorporated	**Comprehensible input**	**Independent**

Integration of Processes	Application	Assessment
Reading	**Hands-on**	**Individual**
Writing	**Meaningful**	**Group**
Speaking	**Linked to objectives**	**Written**
Listening	**Promotes engagement**	**Oral**

Lesson Sequence:

1) **Warm Up:** What is the biggest challenge when using Legos to build?
2) Talk about **constraints**. What are the constraints for the wheelchair challenge?
3) Students will work in teams on the wheel chair challenge.
4) Conclusion: talk about what constraints each team was able to meet.

Figure B-3. The robotics unit: Lesson plan (3).

SIOP Lesson Plan [redacted]

Date: 02/08 & 02/09 **Subject/Grade:** 6th Grade Science

Unit: Engineering Robotics **Standard(s):**

Content Objective(s): Students will be able to research 3 new assistive devices.

Language Objective(s): Students will be able to read about assistive devices.

Key Vocabulary	**Materials**
Research	Computer lab checked out, assistive device research paper, Famous African American paper

SIOP FEATURES

Preparation	Scaffolding	Group Options
Adaptation of content	**Modeling**	**Whole class**
Links to background	Guided practice	**Small groups**
Links to past learning	Independent practice	**Partners**
Strategies incorporated	**Comprehensible input**	**Independent**

Integration of Processes	Application	Assessment
Reading	**Hands-on**	**Individual**
Writing	**Meaningful**	**Group**
Speaking	**Linked to objectives**	**Written**
Listening	**Promotes engagement**	**Oral**

Lesson Sequence:

1) **Warm Up:** Explain what a constraint is.
2) Take notes about how to do research in the lab. Use www.google.com
3) Review assistive devices.
4) Students will use the computers in the Lab to research 3 different assistive devices.
5) If they are done early, they should research about a famous African American Engineer or Scientist.
6) If they finish that, they can create a PPT about their assistive devices they researched.
7) Conclusion: Come back to the room and talk about some of the different assistive devices that they researched and found out about.

Figure B-4. The robotics unit: Lesson plan (4).

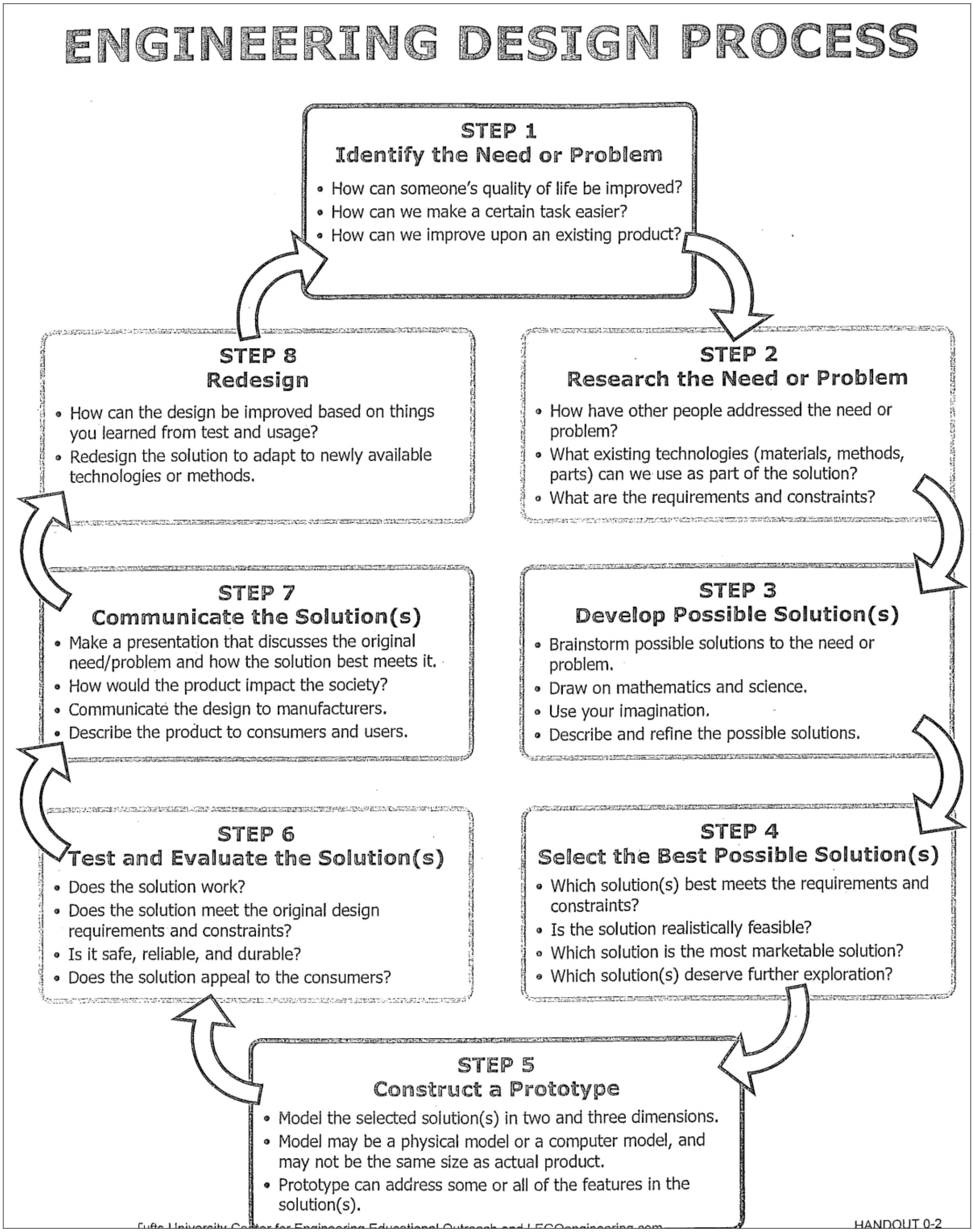


Figure B-5. Robotics unit: Engineering design process.

Name:____________________________________ Block: ________________

Assistive Device/Technology:

____

____

____

Name of Device	Picture/Sketch	Who it helps	Function (what does it do?)

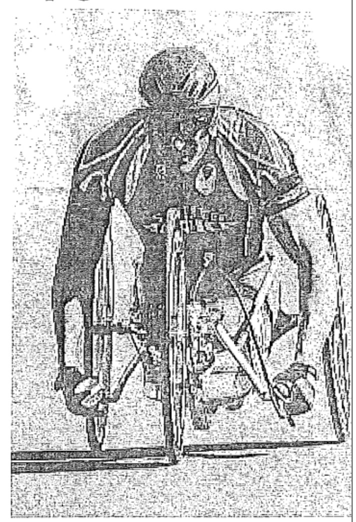
Figure B-6. The robotics unit: Research day student worksheet.

Name ______________________ Date ______________ Block ________

Reading: Paralympic Athletes

Directions:
Read the story below about a REAL Paralympic athlete. When you are finished reading, turn the paper over and answer the questions on the back of this page.

Ernst van Dyk



Name: ERNST VAN DYK
Country: SOUTH AFRICA
Sport: ATHLETICS, CYCLING

If you add the number of miles wheelchair racer Ernst van Dyk races in a season, it's second only to the distance he has to fly to get to the respective starting lines. With South Africa as his home base, Ernst has completed marathons and 10K races in New York, Japan, France, Boston, Atlanta, LA and Sydney. In 2001, he clocked 24 wins on the same international circuit. On 20 April, he won the Boston Marathon for the eight time.

36 year old Ernst was born with congenital birth defects. Soon Ernst's parents recognized his affinity for sports and encouraged him to participate in Gymnastics, Table Tennis, Athletics and Swimming.

Ernst preferred Swimming to all other sports, however, and, by age 17, had won national colors for his aquatic success. In his first Paralympic Games in Barcelona in 1992, he finished fifth place in the pool, while also making it to the semifinals in Athletics wheelchair racing events. Afterwards he concentrated more on wheelchair racing and in 2004 discovered the sport of hand cycling.

At the Beijing 2008 Paralympic Games, Paralympic Ambassador Ernst competed in Athletics and Cycling events and managed to medal in both sports. He wants to keep on pushing the limits in wheelchair racing and hand cycling and is looking ahead to the London 2012 Paralympic Games, where he wants to win two gold medals.

Regardless of his 15 years as an elite competitor, Ernst says his biggest personal accomplishment was earning his university degree, making him the first ever person with a disability to graduate, for a degree in Sport Science, from Stellenbosch University. Ernst currently works as the manager of the Sport Performance division at the Stellenbosch Sport Performance Institute.

Above all, Ernst tries to maintain balance in his life, dedicating time to training, motivational speaking and spending time with his family.

Figure B-7. The robotics unit: An example article for assistive device (1).

Directions:

Read each question below. Use the story on the front of this sheet to answer each question in COMPLETE sentences. You will lose credit for not answering in COMPLETE SENTENCES.

1) Explain what CAUSED this athlete's disability.

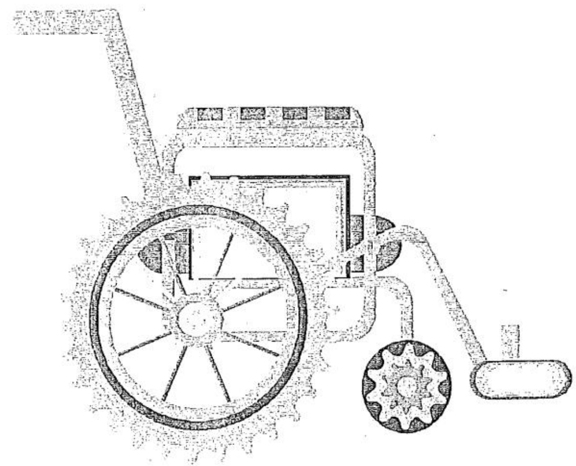
2) Where is this athlete from? What sport(s) does he/she compete in?

3) Describe the assistive or adaptive technology that this athlete uses.

4) Write down 2 other FACTS about this athlete.

Figure B-8. The robotics unit: An example article for assistive device (2).

Wheelchair Design Challenge!



DESIGN REQUIREMENTS:

- ☐ The wheelchair must be at least 8 inches tall.
- ☐ The chair must be able to roll while holding a 1 block + 1lego Person
- ☐ The chair must pass a drop test from 3 feet.
- ☐ The wheelchair can be made from any pieces in your kit EXCEPT FOR the RCX, motors, sensors, and the LEGO tower.

Figure B-9. The robotics unit: Wheelchair design challenge (1).

Sketch your design below:

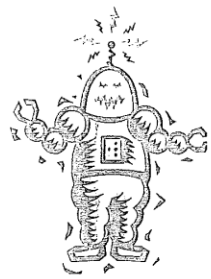
Which parts stayed together during the drop test? How were these parts put together?

What parts did not stay together during the drop test? How can these connections be strengthened?

Figure B-10. The robotics unit: Wheelchair design challenge (2).

Name____Block_______

Engineering Quiz



1. What was one of the constraints for the robotics project?

____

2. What did we research the first time we went to the lab?

____

3. What was the challenge/problem you had to solve for the robotics project?

____

4. Why do engineers make thumbnail sketches?

____

____

5. Why do engineers make a detailed design?

____

____

6. What is the importance of the re-design step in the engineering process?

____

____

7. Why is it important to be able to solve problems on your own?

____

____

____

Figure B-11. The robotics unit: Engineering quiz.

Names: ____Block:___________

ROBOTICS FINAL PROJECT

Step 1: Problem What are we being asked to do?	
Step 2: Constraints How much time do we have to complete the project? What materials are we allowed using?	
Step 3: Research What do we already know about assistive devices?	

Figure B-12. The robotics unit: Final challenge (1).

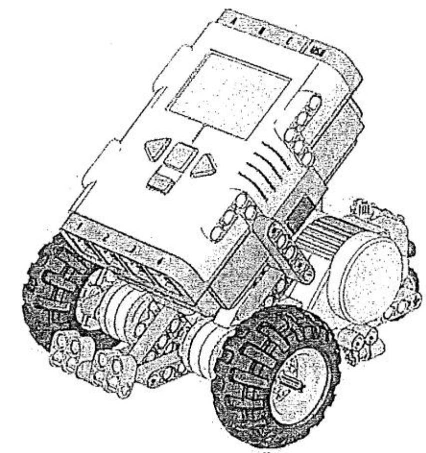
What else did we find out about assistive devices?	
Who do we want to help with our assistive device? Explain why you choose this person(s) to help.	
Explain in detail what you would like your robot to be able to do.	
Explain the types of things you want to include in your robot programming.	

Figure B-13. The robotics unit: Final challenge (2).

Step 4: Thumbnail Designs

Use the information you have about assistive devices and the robotics kits to come up with 2 thumbnail sketch ideas. Describe briefly the purpose of each robot.

Thumbnail Sketch 1:



Thumbnail Sketch 2:

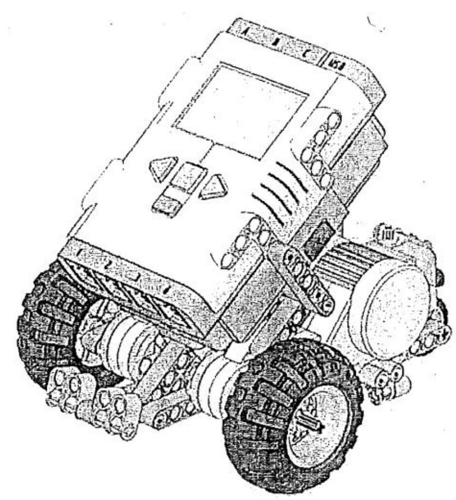


Figure B-14. The robotics unit: Final challenge (3).

Step 5: Detailed Design
Choose one of your thumbnail designs to create a detailed design. This design should have measurements and building instructions. Label measurements as well.
(you don't need to tell how to build the driving base)

Front View

Side View

Figure B-15. The robotics unit: Final challenge (4).

Building Instructions: This is how to put together our robot, starting with the driving base already completed.	
Programming Instructions: This is the program we created for our robot. List all the steps in order.	

Figure B-16. The robotics unit: Final challenge (5).

Step 6: Re-Design What things would you change about the design of your robot? What things would you change about the programming of your robot?	
Problem Solving What were some of the hardest things to problem solve during this final project? How did your team persevere?	
PowerPoint	☐ Title Slide with Company and Robot Name ☐ Picture ☐ What does the robot do? ☐ Who does the robot help? ☐ Why should someone buy your robot?

Figure B-17. The robotics unit: Final challenge (6).

Name____

Partner's Name ____________________________________

Robotics Unit Partner Grading

Rate your partner on the following categories.

5 is the highest, 0 is the lowest.

1. Sharing ideas about the project:	0 1 2 3 4 5
2. Helping design the robot:	0 1 2 3 4 5
3. Staying at the table during work time:	0 1 2 3 4 5
4. Helping program the robot:	0 1 2 3 4 5
5. Overall helped complete the entire project:	0 1 2 3 4 5

Total points ____________/25

Figure B-18. The robotics unit: Peer evaluation sheet.

APPENDIX C

The Genetic Engineering Activity

SCIENCE 7 5-day Cycle (TWO WEEKS) Jan 4 - Jan 19

Day 1 Jan 4 , 5
Content Objective: Students will be able to describe genetic engineering and selective breeding and examples of their benefits to society. **Language Objective:** Students will read, highlight and answer questions about genetic engineering and selective breeding. **Materials**: Articles, GE packets, DVD
Notebook Question (warm-up): Try This: breed a RW (pink snapdragon) with another RW (pink snapdragon) How do the babies look? (this is Incomplete dominance)
Activity 1 – Warm-Up **Activity 2 -** Genetic Engineering flip chart and video clips, introduction **Activity 3:** Genetic Engineering Project – part 1-3 Part 1 – reading articles in pairs, discuss, answer questions in writing Part 2 – Go back to brainstorm section and plan a benefit to society that the GMS might have. Part 3 – Draw and plan Activity 4: Plan what to bring
Reflection: **Be ready to make your organism next time**

Figure C-1. The genetic engineering activity: Lesson plan (1).

Day 2 Jan 6, 7

Content Objective: Students will be able to create a mythical GMO that benefits society in some way.

Language Objective: Students will write about and design on paper or 3D a GMO that is beneficial to society.

Materials:
GMO packets, art supplies

Notebook Question (warm-up):

Describe a real example of a Genetically Modified Organism (GMO)

Activity 1:
Warm-Up

Activity 2: Punnett Square review

Activity 3:

Work on Projects – parts 3 and 4 and final draft

Activity 4:

Present Projects

Homework – finish Punnett square review with incomplete dominance

Figure C-2. The genetic engineering activity: Lesson plan (2).

Genetic Engineering

Names: ______________________________ Date ____________Block __________

In this activity, you get to make up your own fictitious organism - it can be plant, animal, fungi, or one-celled organism. You may create a 2-dimensional organism on paper using crayons, markers, etc. or you may want to use clay, play dough, or other art supplies to create a 3-dimensional model of your organism (you must supply your own materials if you choose this option).

Your organism will be one made through genetic engineering. Since genetic engineering is expensive and time consuming, in order to gain funding to go ahead with your project, you have to prove that the organism is worth creating. It must benefit human society or nature in some way.

STEP 1: What will be your challenge? (What problem will your organism solve? What benefit to society will it have? Why is it worth researching?)

BRAINSTORM: what possible benefits to society do plants and animals have? Think in terms of – what plants and animals are people willing to spend money on because they are good in some way?

If you could create an organism that benefits society or benefits the natural world in some way, what good points would y~~ou you~~'re your organism ~~to~~ have?

STEP 2: Research. Read the research information your teacher provides and text book pages about genetic engineering.

Read the page, "Genetic engineering" Use a highlighter to mark answers to questions or interesting facts as you read.

Questions to answer:

1. How has E. Coli been changed to benefit people?

Figure C-3. The genetic engineering activity: Student package (1).

2. How would "Killer Moths" benefit society?

3. How has the "Spider Rope" gene changed goat's DNA?

Read the Article: "Genetic Modification"

1. On the first page, genetically modified hogs are described. How are they changed?

2. On the 2nd page, 5 possible benefits to GMO's are described. What is one of them?

3. Why do some people think GMO's are bad?

4. One the third page, the good old fashioned way of modifying organisms is described. How have farmers modified plants and animals in the past?

5. One the 4th page, patents are discussed. What is a patent?

6. Describe one of the three crops discussed on the last two pages of the packet:

Describe Genetic Engineering in your own words:

Figure C-4. The genetic engineering activity: Student package (2).

STEP 3: Design. Sketch a rough draft of your genetically modified organism. Be sure to label specific parts which are traits from other organisms.

The original organism: ______________________________

Spliced genes are from: ____

Sketch:

Figure C-5. The genetic engineering activity: Student package (3).

STEP 4: investor approval (testing your product)

Explain why your GMO benefits society or nature in some way. Trade papers with another group. Imagine you are a stock holder in their company. Would you invest money in this project? Do you consider it worth researching? Comment on each other's projects.

How does your GMO benefit society or nature?

____
____
____
____
____
____
____

TRADE PAPERS – this section is to be filled out by another group:

Do you think their product is worth investing in? ______________

Why or Why not?

____
____
____

If you answered NO, what can they do to improve their design to gain your approval?

____
____
____

If you answered YES, what suggestions do you have to improve on their design?

____
____
____

Since we will not REALLY create these GMO's we can't test your designs to see if they really work. But, your final product should be a 3-dimensional model of your organism OR a neatly drawn and colored poster of your organisms.

This packet should be stapled to the back of your poster OR turned in separately if you are creating a 3D model.

Figure C-6. The genetic engineering activity: Student package (4).

ISSUE 2

Genetic modification

Fat facts

Many people have to cut down on the amount of fat they eat because they have heart or blood pressure problems. Most fat from animals is called "saturated" fat. Another type of fat (usually from plants) is called "unsaturated" fat. Unsaturated fat is generally better for you and can help to avoid heart or blood pressure problems. People with these problems are often told by their doctor to eat less meat, butter, and cheese, which come from animals and contain saturated fats. They are advised to eat vegetable oils and nuts, which contain unsaturated fats.

According to some reports, Japanese scientists have been able to put genes from spinach plants into the DNA of hogs. The spinach gene changes the hogs' saturated fat to unsaturated fat. The genetically altered hogs contain 20 percent less saturated fat than normal hogs. This makes products such as pork and bacon healthier to eat.

Some hogs are genetically altered with genes from spinach plants.

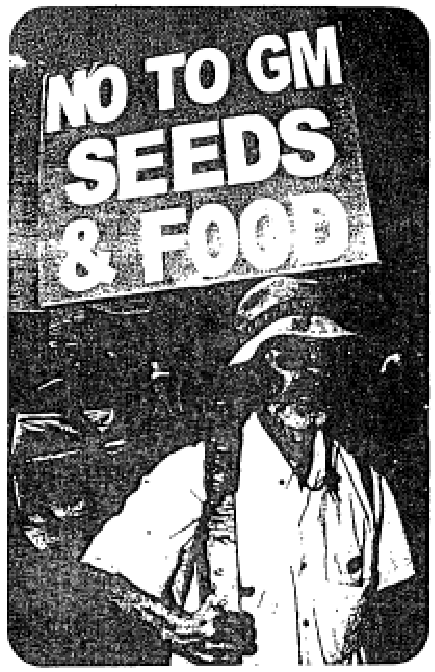
Figure C-7. Genetic engineering activity: Handouts (1).

Genetically modified foods

Changing or modifying the genes of plants and animals in the laboratory is called genetic modification. Foods made from these plants and animals are called genetically modified (GM) foods.

Genetic modification may be used to:

- make foods healthier
- increase the yields of crops
- make crops **resistant** to pests and diseases
- make crops more resistant to chemicals used to kill weeds or other pests
- allow plants and animals to grow in a wider range of climates.



>>
These people are protesting about genetically modified foods and seeds. Some people are not yet sure if GM foods are safe to eat.

What are the issues about genetic modification?

The way that scientists make GM foods is very new. Not many people properly understand the process. When people do not understand something new, they are often afraid of it.

People are naturally careful about what they eat. They like to know that their food is healthy and safe. Many people believe that GM foods should be tested for a few more years before they are sold. Some people believe that GM foods should be banned.

Other people think the world's population is growing so quickly that we will not be able to produce enough to feed everyone. They believe that unless we make GM crops that use less land, water, and **pesticides**, there will be widespread starvation.

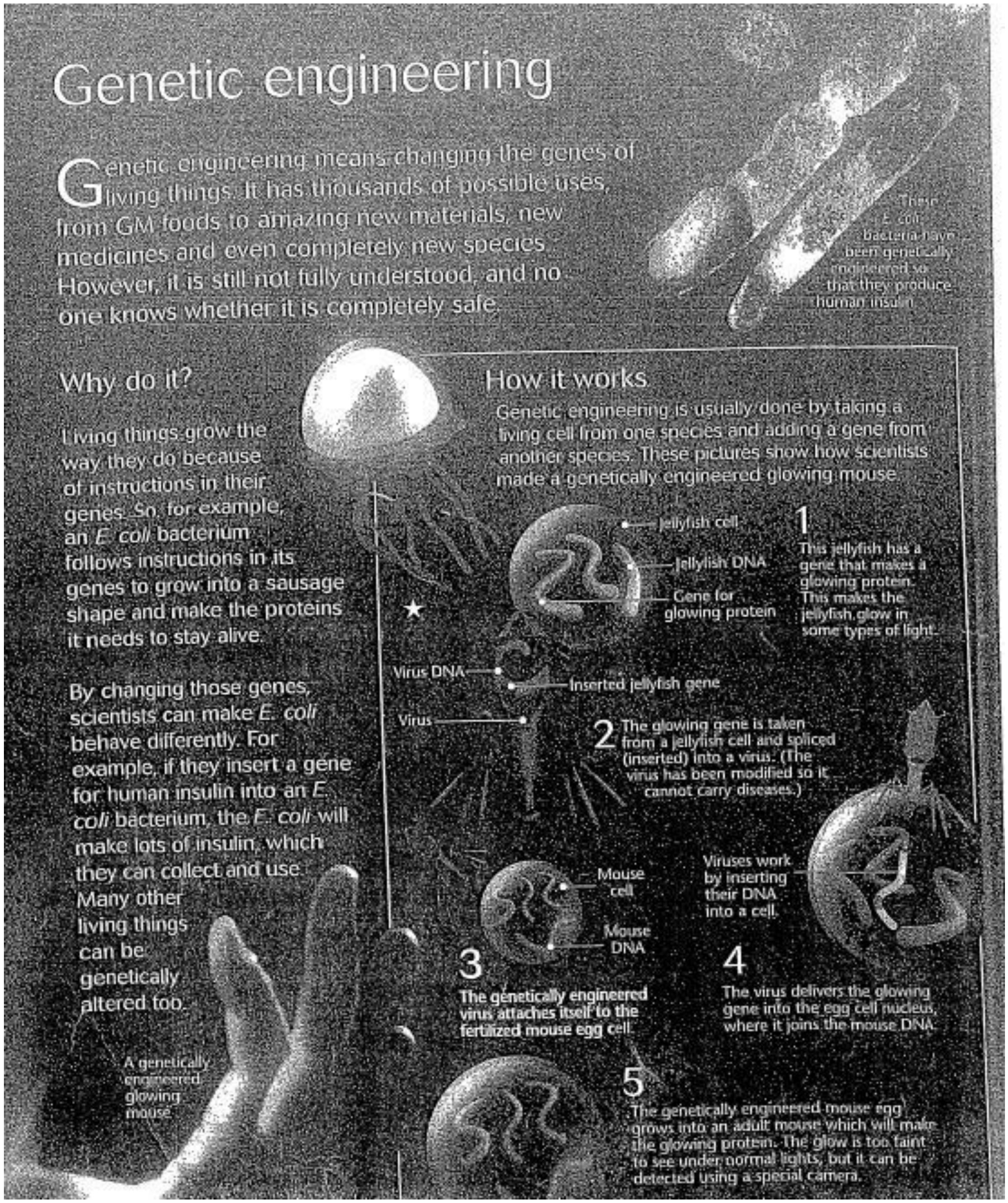
Are GM foods safe?

Is genetic modification okay if it does not involve the food we eat?

Can genetic modification improve our health?

Is genetic modification interfering with nature?

Figure C-8. Genetic engineering activity: Handouts (2).



Genetic engineering

Genetic engineering means changing the genes of living things. It has thousands of possible uses, from GM foods to amazing new materials, new medicines and even completely new species. However, it is still not fully understood, and no one knows whether it is completely safe.

These *E. coli* bacteria have been genetically engineered so that they produce human insulin.

Why do it?

Living things grow the way they do because of instructions in their genes. So, for example, an *E. coli* bacterium follows instructions in its genes to grow into a sausage shape and make the proteins it needs to stay alive.

By changing those genes, scientists can make *E. coli* behave differently. For example, if they insert a gene for human insulin into an *E. coli* bacterium, the *E. coli* will make lots of insulin, which they can collect and use. Many other living things can be genetically altered too.

A genetically engineered glowing mouse

How it works

Genetic engineering is usually done by taking a living cell from one species and adding a gene from another species. These pictures show how scientists made a genetically engineered glowing mouse.

1 This jellyfish has a gene that makes a glowing protein. This makes the jellyfish glow in some types of light.

2 The glowing gene is taken from a jellyfish cell and spliced (inserted) into a virus. (The virus has been modified so it cannot carry diseases.)

3 The genetically engineered virus attaches itself to the fertilized mouse egg cell.

4 The virus delivers the glowing gene into the egg cell nucleus, where it joins the mouse DNA.

5 The genetically engineered mouse egg grows into an adult mouse which will make the glowing protein. The glow is too faint to see under normal lights, but it can be detected using a special camera.

Figure C-9. Genetic engineering activity: Handouts (3).

Genetic Engineering Project – Grade Rubric – total 30 pts

Names: ______________________and ________________________

Packet completed accurately: 10 pts _______

Poster / 3D organism (must have a mini – poster) 15 pts
*Catchy name to help market the organism to investors 3 pts _____
*The features that make the organism different from the original are clearly drawn and labeled. 3 pts _____
*Creativity/originality 3 pts ______
*The organism's BENEFITS to society are clearly explained in 2-3 sentences ON THE POSTER. 4 pts ____
*Neatness ____ 2pts

Presentation - ______ 5pts

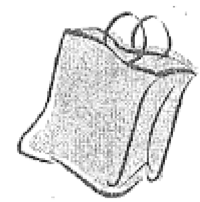
*A convincing explanation of your organism's benefits presented to the class AND you are an appropriate audience during other's presentations.

Figure C-10. Genetic engineering activity Rubric.

Appendix D

Candy Bag Activity

Design and Build a Better Candy Bag



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Lesson Focus

Demonstrate how product design differences can affect the success of a final product -- in this case a bag for holding candy. Students work in pairs to evaluate, design, and build a better candy bag.

Lesson Synopsis

The Design and Build a Better Candy Bag activity encourages students to work in pairs to design, build, and test a candy bag. Students will predict the volume and strength of their original design, sketch the design, create a model candy bag, and then test their bag using weight. After testing, students redesign their bag to improve it, and then retest. Student pairs make predictions, compare results, and discuss their findings.

Age Levels

8-18.

Objectives

- Learn how design impacts product performance.
- Design a better candy bag using science, mathematics, and engineering concepts and applications.
- Build a better candy bag using science, mathematics and engineering design concepts and applications.
- Use the engineering design process to solve the problem.
- Employ the use of data collection and analysis to help solve the problem.

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- engineering design process
- teamwork in the design process
- making and testing predictions
- product design challenges

Lesson Activities

Student teams will design a candy bag, and predict the volume and strength of their design. Students then build a model of their design, redesign it, build an improved bag, retest using weight, discuss findings, and share results.

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Figure D-1. Candy bag activity: Lesson plan (1).

Resources/Materials

- Teacher Resource Documents (attached)
- Student Worksheets (attached)
- Student Resource Sheets (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- TryEngineering (www.tryengineering.org)
- Project Lead the Way (www.pltw.org)
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/TAA)
- National Science Education Standards (www.nsta.org/standards)
- National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (www.nctm.org/standards)

Recommended Reading

- Margaret Knight: Girl Inventor, by Marlene Targ Brill (Millbrook Press, ISBN: 0761317562)
- Packaging Prototypes: Design Fundamentals, by Edward Denison and Richard Cawthray (Rotovision, ISBN: 2880463890)
- 50 Trade Secrets of Great Design: Packaging, by Stafford Cliff (Rockport Publishers, ISBN: 1564968723)

Optional Writing Activity

- Write an essay (or paragraph) explaining how a cardboard milk carton has been designed to be strong enough to hold its liquid contents.

References

Pam Newberry, Project Lead the Way (www.pltw.org)
Doug Gorham, IEEE

Figure D-2. Candy bag activity: Lesson plan (2).

Design and Build a Better Candy Bag

For Teachers: Alignment to Curriculum Frameworks

Note: All Lesson Plans in this series are aligned to the U.S. National Science Education Standards (produced by the National Research Council and endorsed by the National Science Teachers Association), and if applicable, to the International Technology Education Association's Standards for Technological Literacy and the National Council of Teachers of Mathematics' Principles and Standards for School Mathematics.

◈National Science Education Standards Grades K-4 (ages 4 - 9)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- Properties of objects and materials

◈National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- Properties and changes of properties in matter

◈Principles and Standards for School Mathematics (ages 6 - 18)

Data Analysis and Probability Standards

- Instructional programs from prekindergarten through grade 12 should enable all students to:

- formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- develop and evaluate inferences and predictions that are based on data.

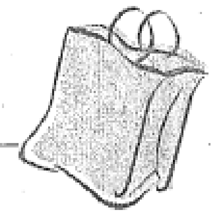
◈Standards for Technological Literacy - All Ages

Design

- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 9: Students will develop an understanding of engineering design.
- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Figure D-3. Candy bag activity: Lesson plan (3).

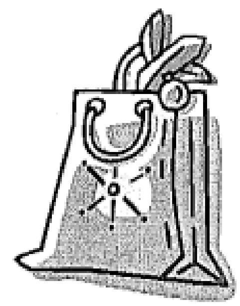
Design and Build a Better Candy Bag



For Teachers: Teacher Resources

◆ Materials

- Student Worksheet
- Sketch paper and pencil
- 8" x 12" pieces of thin, plastic material (we suggest cutting either a plastic painters drop cloth or plastic sheeting)
- Masking tape
- Twine
- Rulers
- Scissors
- Crayons
- Scale, such as spring scale
- Measuring cups
- Books, various sizes of small bottles filled with water, bags of candy, blocks, or other objects to be used as weights
- Items to check for weight, such as rice or candy

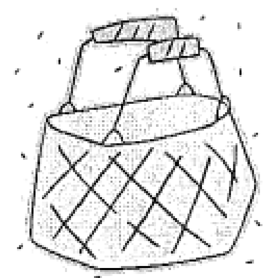


◆ Time Needed

Two Class Periods

◆ Procedure

1. Divide students into pairs and provide the Student Reference Sheet to each. (Note: This sheet can be provided as a reading homework assignment for the prior evening.)
2. Discuss the manufacture of paper bags, and provide several examples of bag designs to share. Ask students to compare the bag designs and guess which might hold the most volume and the most weight.
3. Provide each student with the Student Worksheets and review the project with the teams. Teams will:
   - design a candy bag
   - create a model of their bag design
   - predict the bag's volume and weight capacity
   - test the bag for volume and weight capacity
   - force the bag to fail with too much weight
   - redesign their bag with a goal of holding more weight
   - build a model of the improved design
   - test the second model
   - complete the student worksheet
   - present their finding to the class and compare/contrast results



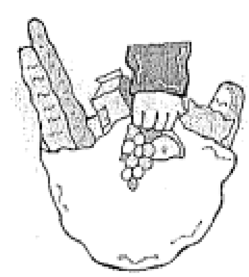


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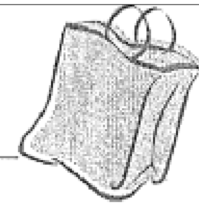
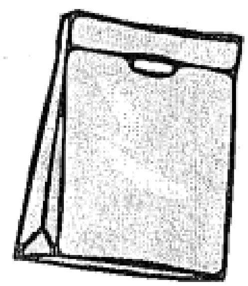
Figure D-4. Candy bag activity: Lesson plan (4).

Design and Build a Better Candy Bag

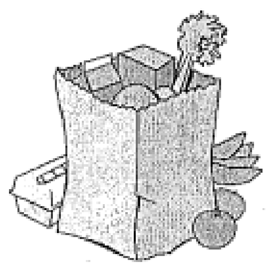


Student Resource: Paper Bag History and Inventors

◆ Paper Bag History and Inventors



Over the years a variety of designs for candy bags have been created. They are built of a variety of materials (paper, plastic, cardboard) and are designed in a variety of shapes. A woman inventor from York, ME, named Margaret Knight (1838-1914) is credited with inventing a process for automatically folding and gluing paper to form the square or rectangular bottom of a paper bag. As a child, Margaret was often designing, or redesigning mechanical p arts for everything fro m kites to sleds. When she grew up, she initially worked at the Columbia Paper Bag Company in Springfield, MA. At the time, paper bags were folded and glued much like envelopes. After her work hours, Margaret began to design a machine part that would automatically fold and glue the square or rectangular bottoms needed for paper bags.



Finally, she came up with a design that she thought would work. She had a Boston machinist create an iron model of the part so that she could apply for a design patent. Initially, her design was ignored as the workmen in the factory questioned what a "woman would know about machine design." Margaret Knight did receive a patent for her machine in 1870, but she had to go through a lawsuit first with a man named Charles Annan who had attempted to steal her design and patent the machine himself! Now, Margaret Knight is often considered the mother of the grocery bag. She eventually partnered with a Newton, MA man and started a company in Hartford, CT in 1870 with her invention: the Eastern Paper Bag Company. Now, Margaret's machine is on display at the Smithsonian Institution in Washington, DC. Visit www.smithsonianlegacies.si.edu/objectdescription.cfm?ID=92 to view a photo of her machine.

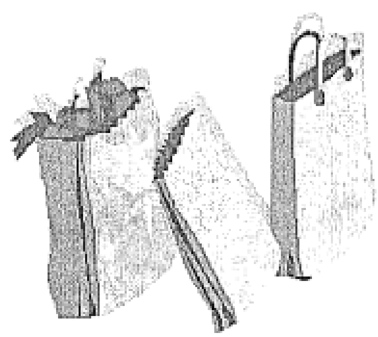


Figure D-5. Candy bag activity: Lesson plan (5). Article about paper bag history and inventors.

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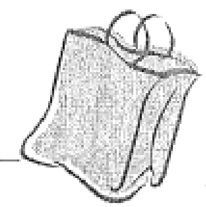


Student Resource: Student Challenge

◆ Student Challenge

You and your partner are employees of the Sweet-Tooth Candy store. Recently your boss has learned that customers would like to have a candy bag that is attractive and more functional than the one they currently use when they shop in the store. Your boss has asked you to design and build a new and improved candy bag that is sturdy, functional, and attractive. She is interested in a candy bag that is able to hold maximum weight and that is attractive, but she has not specified minimum dimensions or the amount of weight the bag must hold.

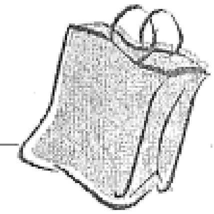
You have learned that the design and construction method as well as materials used will determine the strength of a bag. You will want to test the strength of your candy bag and will redesign and retest as needed. Measurements may be taken to determine how to improve the strength of your candy bag and to estimate the volume or weight the bag will hold.

The Task

1. As a team, discuss and agree upon a design for your candy bag (Note: If you decide to cut the bag, remove no more than 2" from the height of the bag)
2. Draw a sketch of your design in the attached Student Worksheet
3. Build a prototype candy bag based on your design
4. Calculate the approximate volume of the bag
5. Predict how much weight the bag might hold (Note: One 8 oz. bottle of water weighs 9.7 ounces)
6. Test the strength of your candy bag by holding the bag by the handles and placing weight in the bag until it breaks
7. Discuss and agree upon a redesigned candy bag
8. Draw a sketch of your new design in the attached Student Worksheet
9. Rebuild your prototype bag based on your agreed upon redesign
10. Test the strength of your improved candy bag design
11. Present your groups' findings to the class

Figure D-6. Candy bag activity: Lesson plan (6).

Design and Build a Better Candy Bag



Student Worksheet:
Design a Better Candy Bag

◆ Candy Bag Designs
In the box below, draw the candy bag your team agreed upon for your first design. Include how large it will be, a list of materials needed to construct it, and your estimate of how much weight it will hold.

Materials Needed:

Estimated Volume:

Estimated Weight The Bag Can Hold:

Actual Volume:

Actual Weight The Bag Can Hold:

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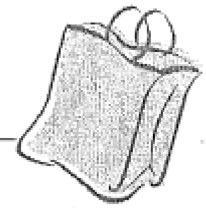
Figure D-7. Candy bag activity: Student worksheet (1).

Design and Build a Better Candy Bag



Student Worksheet: Design a Better Candy Bag

◆ **Candy Bag Designs**

After you have tested your original design and added enough weight to break the bag, redesign your bag, and draw the new design in the box below.

How did this design differ from the prior design?

New Estimated Volume:

New Estimated The Bag Can Hold:

Actual Volume:

Actual Weight The Bag Can Hold:

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Figure D-8. Candy bag activity: Student worksheet (2).

Design and Build a Better Candy Bag

Design a Better Candy Bag

◆ Results

Once you have built your candy bag and tested it, complete the questions below.

1. When you tested your prototype, what was the approximate volume of the bag?

2. How much weight did your bag hold?

3. Did you have to redesign your initial prototype?
   If so, why? What did you discover because of your redesign?
   If not, why do you believe your prototype worked so well the first time?

4. The one thing I liked about our design was...

5. The one thing I didn't like about our design was...

6. The one thing I would change about our design based on my experience is ...

What technology, science, and mathematics concepts did you use when you designed the prototype?

Candy Bag Budget- Original Design

Material	Amount	Cost each	Total Cost	Received
Plastic				
Twine				
Masking Tape				
TOTAL COST				

Candy Bag Budget- Re-Design

Material	Amount	Cost each	Total Cost	Received
Plastic				
Twine				
Masking Tape				
TOTAL COST				

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Figure D-9. Candy bag activity: Student worksheet (3).

APPENDIX E

Genetic Engineering Project

Genetic Engineering Lesson Plan Outline – [redacted]

Description of the Class:

Biotechnology is a one-semester science elective class comprised of 75% seniors and 25% juniors. All students need to have successfully completed biology. The class had a good mix of students took the class because they were truly interested in the topic and of students who took it because they needed a science credit.

Throughout the course, we focused on genetic engineering and modification, as well as the ethical end environmental consequences of GMOs. We performed lab activities where we tested foods to see if they were genetically modified. We also created our own GMO in class when we transformed a lab strain of E. coli with a gene from a jelly fish that caused the E. coli to glow.

Description of the Task:

As a final project, I asked students to research a societal problem that could possibly be solved by transforming an organism with a single gene from another species (see attached Challenge handout). The assignment was introduced one day, and students were able to brainstorm and research possible ideas. The following day, I met with each group to help them refine their most "realistic" idea. After the meeting, the groups wrote a one-page description of what biological problem they would try to solve, and what would be the possible source organism for their gene. The groups then used computers in class to research their project and complete their Google Presentation for the next five class periods. The presentations were given over a period of three days. The rubric used to assess the presentation is modified from a project currently used in the freshman biology class at the University of Minnesota.

Timeline:

Thursday, January 13: Introduced project, handed out Challenge Sheet and Project Proposal Paragraph. No computers today, Project Proposal is due tomorrow.

Friday, January 14: Turn in Project Proposal Paragraph, after project is approved, students can start using computers for their research.

Tuesday, January 18 – Monday, January 24: Work time with the computers to research and put together the presentations using Google Presentation. At least once during the week, I met with each group to discuss their project individually. During this time, I showed each group how to use the NCBI website to search for the sequence of their gene. I also handed out the rubric, so each group understood what they needed to include in the presentation. On the final work day, groups volunteered for the presentation order.

Tuesday, January 25 – Thursday, January 27: Group presentations. Presentations were scored using the rubric. After all presentations were completed, students filled out the Group Member Assessment sheet to rate the level of participation for each group member. Grades on the presentation are adjusted according to effort shown by each individual group member.

Figure E-1. Genetic engineering project: Lesson plan (1).

Name:

Hour:

Genetic Engineering Project Proposal Paragraph

Using the space below, write one paragraph that addresses the following points. The paragraph is due by the end of the hour tomorrow. You will not be able to use computers today, but you will have 5 days in class to use the computers to help you research and complete your presentation.

1. The problem you are trying to solve (what organism(s) are involved).
2. Possible ideas on how you will solve it.
    a. What type of gene will you use to transform the involved organisms?
    b. Will you put the new gene into all cells of the organism, or just certain places?
    c. What are some possible sources for the gene you will choose?
3. Possible ethical concerns that could arise from your proposed experiment.

Figure E-2. Genetic engineering project: Lesson plan (2). Proposal paragraph.

Name:

Hour:

Genetic Engineering Group Member Effort Outline

What did ***you*** specifically do for the project?

List ***each*** of your team members below, and explain what ***each one*** did for the project.

Do you think you all deserve the ***same*** grade? ***Why or why not?***

Figure E-3. Genetic engineering project: Lesson plan (3). Group member effort sheet.

Genetic Engineering Project Rubric **Team Members:** ____________________

Presentation Content 100 points	Criteria	Excellent	Very Good	Good	Marginal	Points
Logic for creating this new gene	**Explain ultimate goal for creation of this new gene**					
	Is reason for creating this new gene clearly explained? (10 points)	Uses diagrams, labels, and captions to effectively to explain the logic for the new gene (10 points)	Uses diagrams, labels, and captions effectively, but needs more information or detail to explain the logic for the new gene (8 pts)	Diagrams adequate, but labeling, captions, or information is not adequate to explain the logic for the new gene (6-7 pts)	Diagrams are ineffective in explaining the logic for the new gene(0-5 pts)	
15 points	*Is the reason for creating the gene reasonable? (5 pts)*	Reason for gene is reasonable; gene will clearly have some value to society, business, health, etc.; that value is well described (5 pts)		Reason for gene is not reasonable or is not sufficiently explained to evaluate (0 pt)		
Molecular Engineering strategies	**Provide basic background information about how the appropriate DNA will be identified, isolated, engineered, and inserted.**					
15 points	*What organism will you get the genes, parts of genes, or DNA that you need? How will you insert it into the new organism? (10 pts)*	Explains or provides a diagram that gives an excellent explanation of the genetic parts and overall strategy for creating the new gene and inserting it into a new organism (8-10 pts)		Explanation is present, but does not completely describe the genetic parts and overall strategy for creating the new gene, and inserting it into a new organism. (5-7 pts)	Information provided is unclear; audience would not understand the features of the gene or how it will be inserted into a new organism (0-4 pts)	
	Is the DNA sequence is included in the presentation? (5 pts)	The DNA sequence is present. (5 pts)		No DNA sequence present. (0 pts)		
Consequences of Transformation	**Provide explanation about how your transformed gene will improve the recipient organism.**					
25 points	*How will this new gene affect the organism or cell in which it is expressed? What evidence will you look for to see if the transformation was effective? (25 pts)*	Explains effectively how this new gene will affect the organism or cell and why. Evidence for successful transformation is clearly stated. (23-25 pts)	Slightly unclear explanations on how this new gene will affect the organism or cell and how to tell if transformation was successful. (17-22 pts)	Unclear explanations on how to tell if transformation was successful. No experimental evidence is suggested. (10-16 pts)	No explanations on how to tell if transformation was successful. No experimental evidence is suggested. (0-9 pts)	

Figure E-4. Genetic engineering project: Lesson plan (4). Rubric 1.

Genetic Engineering Project Rubric **Team Members:** ____________________

Present-ation content (cont'd)	Criteria	Excellent	Very Good	Good	Marginal	Points
Ethics	**Discuss the ethical implications of your engineering proposal**					
25 points	*Provide an overview of the ethical issues your projects raises and discuss how they could be managed. (25 pts)*	The discussion of the ethical issues raised by the project emphasizes the specific implications of the project and provides excellent provisions for contending with these issues. (23-25 pts)	The discussion of the ethical issues raised by the project emphasizes somewhat general implications of the project and provides good provisions for contending with these issues. (17-22 pts)	The discussion of the ethical issues raised by the project provides only general considerations and provides only fair provisions for contending with these issues. (10-16 pts)	The discussion of the ethical issues raised by the project is incomplete or missing (0 -9 pts)	
Future studies	**Describe future work**					
10 points	*What work needs to be done in the future to create or test this strategy? (10 pts)*	Comprehensive explanation of the issues that should be addressed to test the effectiveness/safety of the new gene. (8 – 10 pts)	Good explanation of the issues that should be addressed to test the effectiveness/safety of the new gene. (5 -7 pts)	Minimal explanation of the issues that should be addressed to test the effectiveness/safety of the new gene. (3 – 5 pts)	Explanation is missing or seriously flawed (0-2 pts)	
Aesthetics	**Does the use of color and choice of fonts enhance the presentation's impact?**					
10 pts	*Overall appearance (10 pts)*	Very pleasing to look at; particularly good use of color and graphics (10 pts)	Pleasing to look at; good use of color and graphics (7 pts)	Pleasing to look at; colors or organization may distract slightly from effectiveness of poster (3 pts)	Cluttered or sloppy appearance; gives impression of solid mass of text & graphics, little white space (0-2 pts)	
Above and Beyond	**Exceptional features**					
Up to 5 points (extra credit)	*Does anything in the approach or the poster stand out as being particularly creative? (5 pts)*	Extremely creative – highly novel ideas; artistic approach to the poster (5 pts)	Very creative ideas; very artistic or well designed poster (2 pts)	Good work, but doesn't really stand out from average in terms of novelty or creativity of ideas or esthetics, creativity, artistic qualities (0 pts)		

Figure E-5. Genetic engineering project: Lesson plan (5). Rubric 2.

Biotechnology Final Genetic Engineering Project

100 points

CHALLENGE: ***Your team has been hired as scientific consultants to an international biotechnology company. The company has expertise and capabilities to manipulate genes to do anything from treat disease to produce alternative energy. They would like your team to develop an approach for using genes to solve a problem of importance to society. In response to this challenge, your team will:***

1. Determine a socially relevant goal for genetic engineering/biotechnology.
2. Identify the gene or genes of interest that might be used to reach that goal.
3. Determine how and where to express the gene(s) of interest to achieve your goal.

FORMAT OF ASSIGNMENT: ***In-Class Presentation***

1. **Presentation** that explains:
   i) What gene(s) will be expressed & why (What's the purpose for selecting your gene?)
   ii) The DNA sequence (found on www.ncbi.nlm.nih.gov)
   iii) Where you'll get the original DNA and basically how you will "grow" and purify the DNA you need.
   iv) How you will introduce the DNA into the organism (electroporation, heat shock, gene gun/injection), including what kinds of cells (root, heart, skin, leaf) you hope to transfect with the DNA.
   v) How expression of that gene will achieve the result you want.
   vi) The ethical, legal, and moral implications of your project.
   vii) Explain what further research or work would need to be completed to help optimize and perfect your new strategy.
2. **References** (substantial, comprehensive, appropriate, high scientific quality)

Figure E-6. Genetic engineering project: Lesson plan (6). Presentation guideline.

APPENDIX F

Egg Drop Project

Egg Drop Project

Objective: Build a device that can keep an egg from breaking, when dropped from at least 2 meters.

Rules: No Parachutes
Only materials sold in class can be used.
Cheating on materials will cause a fine of double the material cost.
Device must fit in the size restriction box.
Spending limit is $200 (fake money)

Materials/Costs:

straws - $2 per straw
newspaper - $15 a sheet
cotton balls - $8 each
tape - $3 / inch
plastic bags - $25 small
$35 large
plastic cup - $30 each
Styrofoam cup - $20 each

TEST DROP – 1 test drop can be done in the room only with hard boiled egg. Any tests after this cost $30.

Scoring – 20 points for getting your egg to survive all 3 falls

10 points – surviving 2 meters
8 points – surviving 4 meters
2 points – surviving 6 meters

Extra Credit – Points will be given for the devices that allow the egg to survive the fall and are the least expensive to build, also for devices that have the least mass before the egg is added.

Figure F-1. Egg drop project: Lesson plan and student worksheet (1).

Get some ideas

List the pros and cons of each material. Why it is useful and why it might not be needed.

Material	Pros	Cons

Make a Plan – In the space below make a plan of how you think you will use the materials to construct your vehicle for your egg. Use drawing and labels.

Figure F-2. Egg drop project: Lesson plan and student worksheet (2).

Egg Drop Final   Name________________________

Materials – Record your final material list here. This must match your egg drop device or you will be charged double. Also include if you purchased an egg for practice.

Material	Number Used	Total Cost Item
Straws		
Newspaper		
Cotton Balls		
Tape		
Small Plastic Bag		
Large Plastic Bag		
Plastic Cup		
Styrofoam cup		
Test Egg		
	Total Cost of Device	

Questions: Answer with complete sentences

1. **How did you use the materials to take momentum away from the egg slowly so it would not break?**

2. **Look at a device from another group or individual that was very different from yours. What was their strategy for protecting the egg as the momentum changes?**

3. **If you were to start over on this project, what would you do differently (materials or how they are assembled) to improve your device?**

Figure F-3. Egg drop project: Lesson plan and student worksheet (3).