

A DESCRIPTIVE STUDY OF A MIDDLE SCHOOL FACULTY'S IMPLEMENTATION OF
AN INTEGRATED STEM CURRICULUM

by

EUNJEONG KIM

(Under the Direction of J. Steve Oliver)

ABSTRACT

This study was conducted to gain understanding of middle school science teachers' implementation of integrated STEM curricula in the form of project-based learning (PBL). Middle school science teachers' perspectives on the benefits of and challenges to implementation were an outcome of particular interest. Further, this study examined influences on the teachers' PCK associated with implementation of PBL lessons. Finally, this study investigated an administrator's perspectives on implementing integrated STEM curricula and the related obstacles to that implementation.

This study employed qualitative research methodology, specifically a multiple case study. The participants were three sixth grade earth science teachers in a public middle school which was moving toward teaching science as integrated STEM. Data were collected from various sources including semi-structured interviews, observations, teachers' instructional materials, field notes, and student work samples. Thematic analysis was used for data analysis in this study. Data analysis was conducted including open coding and constant comparative analysis with qualitative data analysis computer software, NVivo 12.

The results showed that the participating science teachers perceived student learning of real-world applications, developing higher-order thinking abilities and teamwork skills, motivation to learn as primary benefits of the PBL lessons. However, they identified a number of challenges including difficulties assessing student achievement, connecting new learning to students' prior learning in the elementary school, limited resources particularly inadequate space, and students' passive learning approach. The participating teachers perceived that their students did acquire understanding of engineering design processes while building products for their projects. The participating teachers' knowledge of instructional strategies for teaching PBL influenced other components of PCK particularly knowledge of orientations to teaching science and knowledge of assessment of student learning. The administrator perceived that STEM is a useful approach for students to develop problem-solving abilities, teamwork skills, and to gain learning experiences with STEM fields.

This study is significant in that it provides a means to better understand in-service science teachers' perspectives on integrated STEM education within an actual implementation. Additional empirical studies focusing on teachers' ongoing difficulties in implementing integrated STEM lessons and the development of teachers' PCK were suggested.

INDEX WORDS: Integrated STEM education, Engineering design process, Pedagogical content knowledge

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EUNJEONG KIM

B.S. Hanyang University, Republic of Korea, 2005

M.S. Hanyang University, Republic of Korea, 2007

B.S. Ewha Womans University, Republic of Korea, 2014

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial
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EUNJEONG KIM

Major Professor:	J. Steve Oliver
Committee:	David F. Jackson
	Joachim Walther
	Barbara A. Crawford

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
August 2019

DEDICATION

To my devoted family and dear friends,

to my husband Bumkil Lee,

and

to my two precious sons Ganghyun Lee and Gangmin Lee

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
CHAPTER	
1 INTRODUCTION	1
Purpose of the Study	5
Research Questions	7
Rationale for the Study	7
Summary	9
2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW	11
Meaning of Integrated STEM Education	12
Engineering Design Process	18
Summary	44
3 METHODOLOGY	45
Data Collection	45
Data Analysis	65
Summary	67
4 FINDINGS	69
Experienced Science Teachers' Perspectives on Integrated STEM Education	70

Benefits of Integrated STEM Education for Student Learning	73
Challenges to Implementing Integrated STEM Lessons	82
Administrator’s Perspectives on Integrated STEM Education	128
Summary	138
5 DISCUSSION AND IMPLICATIONS	140
Benefits of Integrated STEM Lessons for Student Achievement	141
Bridging the Gap between Teachers’ Knowledge and Practice.....	144
Summary	158
REFERENCES	160
APPENDICES	172
A Interview Questions	172
B Observation Protocol	176
C Time Line of the Observation and Interview	178

LIST OF TABLES

	Page
Table 1: Definitions of Integrated Education (Chronological Order).....	13
Table 2: Four Approaches to STEM Education.....	14
Table 3: Characteristics of Scientific Inquiry and Engineering Design (NRC, 2009, p. 40).....	22
Table 4: A comparison of content standard for science as inquiry with scientific and engineering practices (NRC, 2000, p. 18; NRC, 2012, p. 42)	24
Table 5: Sample verbs indicating levels of understanding with the SOLO Taxonomy (retrieved from http://www.johnbiggs.com.au/academic/solo-taxonomy)	37
Table 6: The Goals and Characteristics of Instruction Based on Different Orientations to Teaching Science (Magnusson, Krajcik, & Borko, 1999).....	41
Table 7: Preliminary Survey Questions for the Selection of Participants	49
Table 8: Backgrounds of Participants	50
Table 9: Necessary Evidence to Answer the Research Questions and Ways of Collecting this Data	53
Table 10: Characteristics of Engineering Design and Project-Based Learning.....	97

LIST OF FIGURES

	Page
Figure 1: Framework of the study.....	11
Figure 2: Pictures of the stream activity	58
Figure 3: Pictures of the erosion bottle activity	59
Figure 4: Pictures of the erosion bottle activity at Dan’s class.....	61
Figure 5: Some pictures of Emily’s class	63
Figure 6: Pictures of the evaluation of the final products.....	103
Figure 7: Students’ final erosion bottles in Dan’s class.....	104
Figure 8: Examples of the students’ proposals for presentations	108
Figure 9: Examples of the students’ worksheets.....	109
Figure 10: Turbidity criterion that Chris provided for his students to evaluate clarity	111
Figure 11: A picture of students’ work in Emily’s class	112

CHAPTER 1

INTRODUCTION

The importance of integrated learning of Science, Technology, Mathematics, and Engineering (STEM) has been emphasized over recent decades in science education. The *National Science Education Standards* (NRC, 1996) presented science and technology standards for K-12 education, and the nature of technology and engineering were discussed in *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 2008). Despite many efforts of integration, engineering and technology have not received much attention in science curricula (Achieve, 2013a). However, with the release of the *Next Generation Science Standards* (NGSS), the use of integrated STEM curricula has become an increasingly common instructional practice interpretation of the science standards. In particular, the eight science and engineering practices in the NGSS suggest characteristics for the teaching approaches of integration of engineering, mathematics, and technology in the science classrooms. The major aspects of the rationale for the emphasis on the integration of engineering in science education are discussed below. Three specific aspects will be considered: strengthening the national economic competitiveness through STEM education, developing problem-solving abilities among school-age students, and teaching for understanding of science principles through STEM.

With the current emphasis being placed on the importance of integrated learning and the inclusion of engineering practices in the science curricula, science teachers have been asked to connect the NGSS with their lessons. However, many science teachers have little confidence in teaching integrated content, such as how to include engineering concepts in their lessons

(Cunningham & Carlson, 2014; Honey, Pearson, & Schweingruber, 2014). In this respect, in order to provide appropriate support for teachers this study investigated middle school science teachers' perspectives on STEM education and their challenges to implementing integrated STEM curricula.

A Rationale for STEM

First, *A Framework for K-12 Science Education* (hereafter referred to as The Frameworks) (National Research Council [NRC], 2012) stated that a major role for science education within the larger picture of global competition is strengthening the national competitiveness related to science and engineering: “Many recent calls for improvements in K-12 science education have focused on the need for science and engineering professionals to keep the United States competitive in the international arena” (p. 7). As school systems and curricula have been powerfully influenced by societal responsibilities (Lucena, 2005; Seely, 1999), these social needs were reflected in the NGSS emphasizing an integration of STEM education: “Science is also at the heart of the United States’ ability to continue to innovate, lead, and create the jobs of the future... The U.S. has a leaky K–12 science, technology, engineering and mathematics (STEM) talent pipeline, with too few students entering STEM majors. We need new science standards that stimulate and build interest in STEM” (Achieve, 2013b, pp. 1-4).

Second, integrated learning helps students to develop abilities of solving problems to deal with global challenges such as limited water supply, food shortage, or climate change. Students living in the twenty-first century encounter a number of global issues affecting their lives, and these problems require combined knowledge of multiple disciplines to find solutions. According to the *Framework*, “Science, engineering and the technologies they influence permeate every aspect of modern life... Knowledge of science and engineering is required to engage with the

major public issues of today as well as informed everyday decisions” (NRC, 2012, p. 7). In this respect, integrated learning across the STEM domains is critical as engineering activities engage students in critical analysis of original personalized decision-making (Brophy, Klein, Portsmore, & Rogers, 2008). In addition, the *Framework* stated that students can be motivated to study science and engineering when they recognize that these two disciplines are pivotal to finding solutions to current problems facing society. This motivation to learn and the interest in science and engineering encourage students to pursue careers in STEM fields and ultimately support the nation’s competitiveness.

The third rationale is that problems of engineering and technology help students to understand science principles by providing opportunities to apply scientific knowledge to practical problems in real life. Through the experience of practical application of scientific concepts, students can have a deeper understanding of and interest in science. For example, high school students learn difficult chemistry concepts effectively such as atomic interactions by adapting the iterative learning process of the engineering design approach (Apedoe, Reynolds, Ellefson, & Schunn, 2008). There is no doubt that engineering and technology help students understand science by practical application of scientific knowledge (Duschl & Bybee, 2014; Sun & Strobel, 2014). For the reasons discussed above, the new science standards focus on integrating engineering and technology in science education.

In addition to the rationale, understanding the interdisciplinary relationship between science and engineering sheds light on how to incorporate engineering practices as a component of science education. Science and engineering have similar characteristics such as iterative and systematic processes of investigation (NRC, 2012). On the other hand, while the goal of science is constructing explanations for the phenomena of the world, the goal of engineering is solving

problems derived from human needs. The *Framework* explicitly explains the differences between science and engineering:

In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation (NRC, 2012, p. 68-69).

Science knowledge is fundamental to solve engineering problems, and engineering is a discipline of applying as well as creating tools and technology for developing scientific knowledge that helps deepen the understanding of science. The *Framework* states that “Any education that focuses predominantly on the detailed products of scientific labor - the facts of science - without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering” (NRC, 2012, p. 43).

The Accreditation Board for Engineering and Technology (ABET, 1999) emphasized that rather than simply presenting knowledge, engineering education should focus on the integration of knowledge and the development of critical skills needed to apply it appropriately. Thus, this goal in engineering education is similar to the goal of scientific literacy in science education. Teachers cannot cover the entirety of the wide range of content knowledge needed for students

nor are they prepared to implement fully formed engineering education in this radically changing era. But explicit guidelines incorporating engineering practices as an explicit component of science education, such as the guidelines presented in the NGSS along with intensely focused professional development, can begin the process of full integration. The goal of supporting all students across all demographic descriptions to accomplish higher-order thinking and solving complex problems while also learning conceptual science content can be accomplished.

The history of engineering education has been characterized by cycles of emphasis between attacking practical problems to examining engineering from its scientific base knowledge (Rugarcia, Felder, Woods, & Stice, 2000; Seely, 1999). Carlsen (1998) suggested that the history of science advocates that science has always been more practical and socially relevant than we tend to think. He suggested that the integration of engineering into science education can more easily be accomplished than is typically believed due to this more practical and socially relevant nature of science. Engineering design offers a very complementary means by which to engage students in problem solving and other forms of practical work. In doing this, students from a range of demographic groups can be educationally supported and find greater relevance within the science curriculum.

Purpose of the Study

This study aims to support science teachers in implementing successful integrated STEM lessons to meet NGSS or other state-modified standards. To this end, this study investigates middle school science teachers' perspectives on the benefits of and challenges to implementing STEM curricula, as well as, the shifts in their professional practices in the context of pedagogical content knowledge (PCK). A middle school where this research was conducted was preparing to provide integrated STEM lessons rather than traditional single-subject science classes. The sixth

grade middle school teachers initially implemented the STEM curricula through teaching project-based learning (PBL) lessons. The middle school had a plan to expand the integrated STEM lessons to other grades the following year based on the PBL lessons shown in this study. This transition presents various pedagogical shifts and challenges for teachers who have traditionally taught single-subject science classes. It was the intention of the researcher that the findings of this study would contribute to developing a model or reference for successful implementation of STEM curricula at other schools and other grade levels.

To support science teachers transitioning from teaching traditional single-subject science classes to implementing the integrated STEM lessons, understanding the exact challenges they confront is first and foremost. Defining the specific obstacles is fundamental for providing insights into effective ways to conduct STEM education. As teachers' personal beliefs and knowledge are critical factors that influence their actual teaching (Bartos & Lederman, 2014; Crawford, 2007; Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2008), this study also explores what teachers perceive as the benefits of implementing integrated STEM curricula. Therefore, this study investigates middle school science teachers' perspectives on the implementation of STEM curricula in terms of the challenges and benefits.

Another purpose of the study is to improve our understanding of the influences of the implementation of integrated STEM curricula on middle school science teachers' pedagogical content knowledge (PCK). Teachers' PCK is developed by their experiences and classroom practices (van Driel, Beijaard, & Verloop, 2001) and especially by implementing new instructional strategies (Park & Oliver, 2008a). Despite the previous attempts to combine science and engineering into an integrated discipline, the creation of the NGSS was the first time that this

was formalized into the standards that were to serve as the basis of K-12 science teaching (Achieve, 2013a).

Given that the inclusion of engineering in the science standards is a new phenomenon and science teachers are not sufficiently prepared for integrated STEM education, an understanding of how secondary science teachers develop their PCK through teaching STEM curricula is critical for improving professional development programs. This study explores the impacts of implementing integrated STEM curricula on the six PCK components of the hexagon model by Park and Oliver (2008b): orientations to teaching science, knowledge of assessment of student learning, knowledge of instructional strategies for teaching science, knowledge of science curriculum, knowledge of students' understanding in science, and teacher efficacy. Since teachers' knowledge of science curriculum, for instance, will undergo a revision when shifting to integrated STEM from single-subject science, it is hypothesized that this shift will reverberate throughout the other components of the teachers' PCK.

Research Questions

This study investigates the following research questions:

1. In shifting to a STEM-focused curriculum, what do middle school science teachers perceive as the benefits of and challenges to its implementation?
2. What influences on the components of teachers' pedagogical content knowledge (PCK) can be determined when middle school science teachers implement STEM curricula?

Rationale for the Study

With the inclusion of engineering practices as part of the science standards, determining how to support science teachers as they include integrated content into science instruction is an important issue in science education. Even though many studies about STEM education have

been conducted over the past 10 years, in general, science teachers have considered engineering and technology as separate disciplines from science curricula (Achieve, 2013a). However, with the release of the NGSS, science teachers are widely encouraged to incorporate integrated STEM lessons in their classrooms. This is a tremendous “*conceptual shift*” (Achieve, 2013b) to the STEM curriculum in science education; thus, this study is significant in that it provides insight into the development of the perspectives of science teachers who experience this *conceptual shift*.

Research on the implementation of integrated STEM curricula in science classrooms based on the NGSS is at a starting stage. For instance, a national mixed-methods study of science teachers’ readiness showed that secondary science teachers perceived that limited instructional time, resources, and teacher preparation were barriers for implementing the NGSS in their classrooms (Hagg & Megowan, 2015). Another study indicated that many high school chemistry teachers (160 of the 210 participants) perceived that they did not include engineering practices, as described in the NGSS, in their lessons (Boesdorfer & Staude, 2016). These studies focused on teachers’ perceptions of their teaching environment and their own lessons through self-evaluations. Although self-evaluations can reveal valuable data, additional studies employing various research methods, such as observations, interviews, or student work samples, would provide deeper analysis to explore teachers’ actual practices and their perspectives on integrated learning in real classrooms. In this respect, this study is meaningful in that we can understand in-service teachers’ perspectives and environment based on qualitative research methodology and diverse research methods.

Furthermore, the challenges involved with implementing STEM curricula are not limited to physical/environmental resources. Teachers’ psychological aspects, such as their reluctance to

change their instructional strategies, are also critical factors that influence the success of the new curricula (Borko, 2004; Guskey, 2002). This study aims to provide a deeper and more comprehensive understanding of teachers' perspectives on STEM curricula encompassing both environmental and psychological aspects.

This study is also pivotal in that it attempts to provide an understanding of the influences of the implementation of STEM curriculum on secondary science teachers' PCK in real classroom settings. Research has shown that many teachers have indicated differences between their perspectives and their classroom teaching (Guskey, 2002). Moreover, many studies have been conducted on preservice or elementary teachers' perceptions about integrated lessons or professional development programs for in-service secondary teachers (e.g., Lee et al., 2008; Page, Lewis, Autenrieth, & Butler-Purry, 2013; Stohlmann, Moore, & Roehrig, 2012; Sun & Strobel, 2014).

On the other hand, few studies have investigated in-service science teachers' perspectives and their implementation of integrated STEM lessons based on their real classroom teaching. This study investigates secondary science teachers' perspectives and practices in terms of PCK based on their real classroom teaching. Therefore, this study contributes to obtaining insights into more effective ways to promote science teachers' participation in STEM curricula as well as to design practical professional development programs that provide meaningful support. This study seeks to attain a deeper and more comprehensive understanding of teachers' perspectives regarding the implementation of STEM curricula.

Summary

In this chapter, I have provided a brief discussion on the current issues related to STEM education and presented the purpose of the study, research questions, and the rationale of the

study. In chapter 2, I discuss the theoretical framework for this research and review the literature which informs this framework. First, I explain the benefits of integrated STEM education for students and discuss teachers' difficulties in teaching integrated STEM curricula. Second, I discuss the meaning of engineering design process which was adopted as a framework for this study. Lastly, I discuss teachers' PCK in the context of teaching integrated project-based learning (PBL). In chapter 3, I discuss the research methodology for the study. This research employed qualitative research methodology, specifically multiple case study. I conducted semi-structured individual interviews and observed participants' teaching including traditional science classes and integrated project-based learning lessons. Data consisting of students' samples, their activity products, semi-structured interview, observations, and other artifacts (e.g., presentations), were analyzed based on the thematic analysis method. In chapter 4, I present the findings of this study with four strands. First, I discuss three middle school science teachers' perspectives on integrated STEM education focusing on benefits and challenges of implementation of the project-based learning (PBL) lessons. Second, I present the results of an investigation into the science teachers' teaching of the PBL lessons in terms of the engineering design process. Third, I explore the development of the participating experienced teachers' pedagogical content knowledge (PCK) in the context of the participants' teaching of the PBL lessons. Fourth, I share my analysis of an administrator's perspectives on implementing integrated STEM lessons. In particular, I examine what differences and similarities exist between the administrator's and the science teachers' perspectives on the integrated lessons. In chapter 5, I discuss implications of the study and suggestions for future research.

CHAPTER 2

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

In this chapter, I discuss three strands of literature that provide the theoretical framework for conducting this study about middle school science teachers' perspectives on integrated STEM education as shown in figure 1. First, I explore the meaning of integrated STEM education and teachers' challenges for teaching integrated STEM curricula. Second, I examine the meaning of the engineering design process and project-based learning (PBL) that are fundamental principles of this study. In this study, the participating science teachers adopted PBL as a way of implementing integrated STEM lessons and the PBL lessons included diverse aspects of the engineering design process. Furthermore, PBL and the engineering design process exhibited similar characteristics in this study. Third, I explore six components of pedagogical content

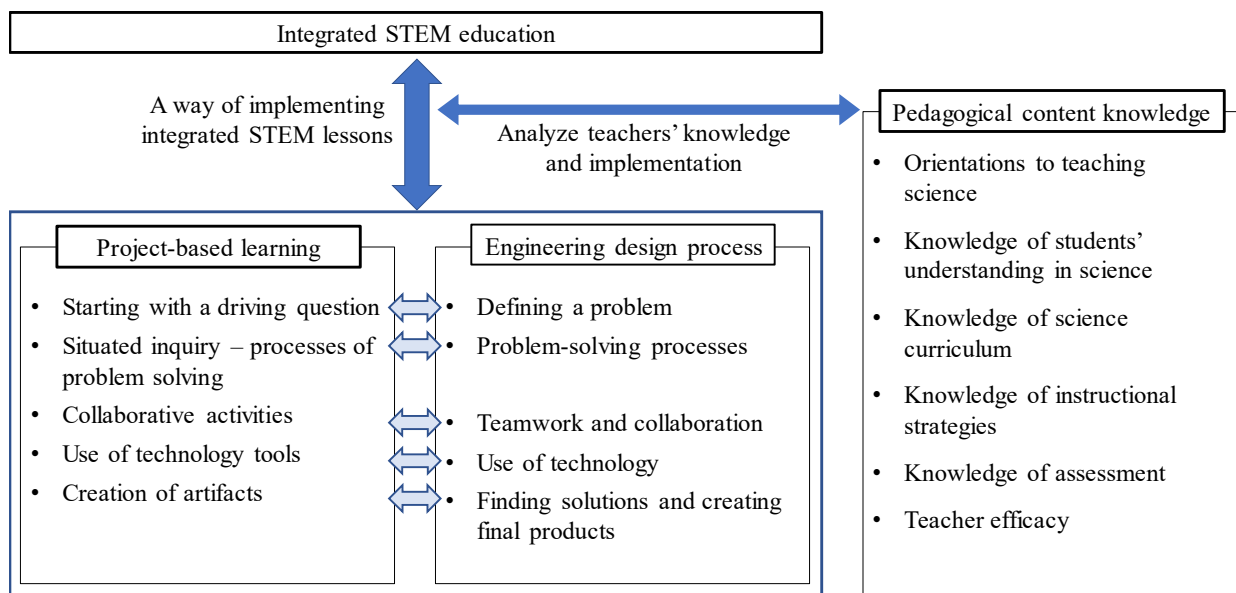


Figure 1. Framework of the study.

knowledge (PCK) that provide a framework to analyze the participating teachers' beliefs and knowledge.

Meaning of Integrated STEM Education

Even though many educators have made serious efforts to integrate curricula in science education, there is still no consensus on the definition of integrated STEM education. Clarifying the definition is essential for designing and implementing research on integrated lessons and for discussing appropriate strategies for the successful implementation of integrated STEM education. In this study, I discuss a variety of definitions of integrated STEM education and also put forward an operation for this study.

Integration of Curricula

Various curriculum design formats for integration of science and mathematics have been suggested: independent science or mathematics, science focus (math as a subset of science), mathematics focus (science as a subset of mathematics), some overlap between science and math, and a major overlapped program (Czerniak, Weber, Sandmann, & Ahern, 1999; Jacobs, 1989; Lonning & Defranco, 1997) (see Table 1). These concepts are described as five forms of curriculum integration: *sequenced*, *parallel*, *partial*, *enhanced*, and *total* (Hurley, 2001).

Davison, Miller, and Metheny (1995) suggested five types of integration for developing integrated curriculum: discipline specific (e.g., integration within a discipline), content specific (e.g., integration of mathematical and scientific concepts), process (e.g., integration of scientific processes such as collecting data and mathematics standards such as statistics), methodological (e.g., integration of the learning cycle for teaching science and teaching and learning models in mathematics), and thematic integration (e.g., thematic topics for integration between disciplines).

Table 1

Definitions of Integrated Education (Chronological Order)

Author(s)	Content	Definition
Jacobs, 1989	Curriculum design options	Parallel disciplines, multidisciplinary, interdisciplinary, integrated, and complete program
Davison, Miller, & Metheny, 1995	Five types of integration	Discipline-specific, content-specific, process, methodological, thematic integration
Lonning and DeFranco, 1997	Comparable continuum of integration for science and mathematics	Independent mathematics, mathematics focus, balanced mathematics and science, science focus, and independent science
Hurley, 2001	Five curriculum forms	Sequenced, parallel, partial, enhanced, and total curriculum integration
Sanders, 2009	Integrative approaches to STEM education	Teaching and learning between/among any two or more of the STEM subject areas
Bybee, 2010	Five meanings of STEM	Recognition of the end of diminishing science education during the NCLB era, the emphasis of technology, engineering in K-12 education, opportunities for stressing twenty-first century skills, and an integrated curricula approach
Johnson, 2013	Approaches for STEM programs	STEM enhanced model and integrated STEM model

Sanders (2009) literally presented the meaning of STEM education in terms of the integration of subjects. He defined integrative STEM education as approaches of “teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects” (p. 21). The author emphasized “purposeful design and inquiry” pedagogy to implement successful integrative STEM education.

Bybee (2010) presented five meanings of STEM in terms of a vision for preparing for the twenty-first century. First, STEM means recognition of the end of what has been characterized as diminishing science education during the *No Child Left Behind* era. Second, he asserted that STEM should mean increased emphasis on technology and, third, increased focus on engineering in K-12 education. Fourth, the STEM acronym means that STEM disciplines provide

opportunities to develop twenty-first century skills. Fifth, STEM means an integrated curricular approach to deal with global issues such as energy efficiency or environmental quality. Bybee suggested six global issues that should be dealt with within the context of STEM education: health, energy efficiency, natural resources, environmental quality, hazard mitigation, and frontiers of science, technology, engineering, and mathematics. He suggested STEM competencies for students to achieve in the twenty-first century; identifying STEM issues, explaining issues from STEM perspectives, and using STEM information.

In a similar vein, integrated STEM education can be described based on the implementation methods: add-on coursework within current curricula and the new stand-alone coursework. The add-on approach includes two methods of implementation: adding additional coursework of each discipline and adding the new STEM coursework with an interdisciplinary format. The stand-alone approach for integrated STEM focused on developing integration of STEM disciplines with real-world problems (Johnson, 2013).

Four Approaches to STEM Education

In this study, I conceptualized four approaches to STEM education that arose from my synthesis of the literature. These four approaches have been labeled as: the illusion approach, the enhanced approach, the generalized approach, and the specialized approach (see Table 2). The

Table 2

Four Approaches to STEM Education

Approaches to STEM Education	Meaning of the Approach
Illusion Approach	Not new and already exists as an instructional method
Enhanced Approach	Focuses on science and mathematics education
Generalized Approach	Emphasis on outcomes through implementing integrated STEM education
Specialized Approach	Integration of two or more subjects

illusion approach happens when the teacher perceives that STEM education does not represent a unique approach and that the term STEM, which already existed as an instructional method, is a response to the social needs based on economic or global pressure. Advocates of this perspective insists that teachers have been teaching STEM lessons and thus new instructional strategies are not needed for teaching integrated STEM lessons (e.g., see Akerson et al., 2018). The illusion perspective usually appears when new teaching and learning approaches are presented.

The enhanced approach is in evidence when stakeholders perceive that STEM education has been implemented to support science or mathematics education by the integration of other disciplines, particularly technology and engineering (Lederman & Lederman, 2013; Roehrig, Moore, Wang, & Park, 2012). This approach focuses on science or mathematics education and considers technology and engineering as supportive disciplines.

The generalized approach occurs when stakeholders perceive that the term STEM education refers to education in each of the STEM disciplines. For example, the National Science Foundation (NSF) has used STEM to indicate the four disciplines of science, technology, engineering, and mathematics (Sanders, 2009). This generalized approach does not assert integration of all four disciplines but rather focus on the outcomes through implementing integrated STEM education such as improvement of student achievement or interests of careers in STEM fields.

The specialized approach perceives that STEM education refers to integrated instruction in STEM disciplines. This approach happens when stakeholders perceive that STEM curriculum can combine any of the four STEM disciplines (Sanders, 2009).

For this study, the most common implementation is the specialized approach of STEM education, which means that STEM curriculum integrates two or more subjects of STEM

disciplines. In this study, the participating science teachers employed project-based learning (PBL) lessons as a method of implementing STEM education. As the PBL lessons included knowledge of science, mathematics, engineering, and technology, I considered that these PBL lessons were appropriate for implementing the STEM curriculum.

Why Do We Need Integrated STEM Education?

The number of students who pursue degrees in STEM disciplines has continuously decreased and the lack of workforce in STEM fields is considered an obstacle to enhancing national competitiveness (Brophy et al., 2008; Lucena, 2005; NRC, 2009; Johnson, 2013; Sanders, 2009). Also, students who live in the twenty-first century have educative needs to cultivate interdisciplinary skills including problem-solving ability, teamwork, creativity, and communication skills to cope with the globalized environment (ABET 2014; Brophy et al., 2008; Johnson, 2013). This phenomenon points to the failure of the conventional teaching pedagogy and to the need to implement the new teaching and learning approach representing integrated STEM education.

Integrated STEM education helps students develop the interdisciplinary abilities mentioned above as well as self-guided inquiry skills by providing opportunities to engage in problem-solving activities (Fleer, 2000; Sadler, Coyle, & Schwartz, 2000). Moreover, integrated STEM lessons are effective methods for improving student achievement and interest in science and motivation to learn (Apedoe et al., 2008; Duschl & Bybee, 2014; Sadler et al., 2000).

More specifically, as engineering design activities fundamentally require knowledge of science, mathematics, and technology, they help students understand science concepts and their applications. Students learn cognitive and logical thinking skills while conducting evaluation and optimization processes of engineering design, and this results in better understanding of difficult

science concepts. For instance, high school students effectively learned difficult chemistry concepts, such as atomic interactions and reactions, by adapting the engineering design unit of heating and cooling systems within an iterative learning cycle (Sadler et al., 2000).

One notable finding from the research on student learning through engineering design activities was their positive impact on the achievement of students who were in low socio-economic areas, special education students (IEP), and female students (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Mehalik, Doppelt, & Schunn, 2008; Sadler et al., 2000; Silk, Schunn, & Cary, 2009). Using engineering design-based activities was an effective strategy for reducing achievement gaps in science. For example, African American middle school students in engineering design groups achieved higher science knowledge performance scores than did the students in a traditional teaching method group (Mehalik et al., 2008). Similarly, achievement gaps in science were diminished for middle school special education students when they participated in the engineering design modules (Cantrell et al., 2006). Integrated engineering content within science curricula offered a complementary means by which to engage students in problem solving and inquiry activities. By participating in an integrated STEM lesson, students from a range of demographic groups were educationally supported and found relevance and need-to-know within the science curriculum. The engineering activities provided motivation for learning by suggesting reasons to know by the students themselves and opportunities to ask questions and design experiments of their own. Moreover, students had positive attitudes about STEM careers after conducting STEM activities.

Moreover, since engineering content is related to real-life problems, students also show interest in and motivation for learning by engaging with familiar topics. In addition, engineering design is a social and collaborative process that encourages students to develop teamwork and

communication abilities. As engineering tasks are undertaken to satisfy others' needs, students should consider different perspectives and other people's opinions. By doing this, students can explore diverse views and cultural differences that are vital to a twenty-first century global society. To obtain these benefits of integrated STEM education, teachers' abilities to teach integrated curricula are critical. Therefore, we need to understand teachers' perspectives, including possible difficulties in, knowledge about, and reluctance to teach STEM education.

Engineering Design Process

With its the eight scientific and engineering practices, the NGSS focus on the engineering design process among a variety of aspects in engineering. *A Framework for K-12 Science Education* (NRC, 2012) presents the importance of teaching the engineering design process in science classrooms: "Defining and solving the problem... are the parts of engineering on which we focus in the framework, both because they provide students a place to practice the application of their understanding of science and because the design process is an important way for K-12 students to develop an understanding of engineering as a discipline and as a possible career path" (NRC, 2012, pp. 27-28). The role of engineering design in science education is usually considered a novel way of applying scientific knowledge or learning to find solutions (Sun & Strobel, 2014). On the other hand, the ability to design an engineering process is considered one of the key components of engineering that students should achieve in engineering education (Banios, 1991; NRC, 2009).

Even though scholars have not reached a consensus about the definition of engineering design, according to *Engineering in K-12 Education* (NRC, 2009), engineering design is "the approach engineers use to solve engineering problems – generally, to determine the best way to make a device or process that serves a particular purpose" (p. 38). In general, it follows a

systematic process that largely includes six steps: identifying problems, generating ideas, developing a model, evaluating possible solutions, optimizing the solutions, and finding final solutions. Each step involves several specific processes/practices.

Identifying problems includes two practices: defining problems and identifying specifications and constraints. This can be understood as the inherent characteristics of the engineering profession. As engineering tasks are undertaken to satisfy others' needs, engineering design is purposeful: "Engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved" (NRC, 2012, p. 50).

Also, engineering design is specified within constraints. Engineers have specifications that they have to accomplish within realistic limitations, such as costs or available materials. Basically, engineers work for a client, such as the government or corporations; therefore, they try to meet the client's requirements when they design solutions with restricted resources. According to the Accreditation Board for Engineering and Technology (ABET, 2014), one of the student outcomes that students should attain in engineering is "an ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (p. 3).

Generating ideas requires engineers to do research or brainstorm to develop several solutions to the problems. Engineers develop models or prototypes and test them in order to evaluate strengths and weaknesses of potential solutions. From these modeling and testing processes, engineers obtain the data and analyze them to determine if the possible solutions meet the needs and specifications of the clients (NRC, 2009).

After evaluating alternatives, engineers select the best solution and optimize it. In engineering, there is usually not just one correct solution. Among various possible solutions,

engineers select the best solution that balances out the desired functions and the constraints. This trade-offs process is essential for the optimization of the selected solution to improve the functions within the given constraints (NRC, 2009).

These design processes are non-linear, and engineers often repeat the design processes at points within the process that they deem necessary. For example, if developed solutions fail to pass specifications, they go back to the first step, identifying problems, or to the second step, generating ideas. If engineers cannot come up with possible solutions, they also go back to the first step. Or, engineers often just repeat the evaluation process, building and testing models and prototypes, to generate data for choosing a solution. This is the iterative characteristic of engineering.

After several iterations, engineers decide the final and the best solution to satisfy the client's needs, specifications, and constraints. Usually, there is no perfect solution but rather the best solution within the real-world environment.

Similarities and Differences between Science and Engineering

In this section, I discuss characteristics of science and engineering and their definitions focusing on similarities and differences. In general, as these two disciplines are intertwined, it is difficult to exactly separate them in real life. However, science and engineering have their own specific characteristics, so I focus on similarities and differences of the two disciplines. As there is no consensus on these issues among scholars, I initially confine my discussion to the rigorous documents, *Engineering in K-12 Education* (NRC, 2009) and *A Framework for K-12 Science Education* (NRC, 2012).

Engineering in K-12 Education (NRC, 2009) defines engineering as “the process of designing the human-made world... [science] is commonly described as the study of the natural

world” (p. 27). The *Framework* defines the meaning of science based on the general perspective to present their new standards for teaching science: “In the K-12 context, science is generally taken to mean the traditional natural sciences: physics, chemistry, biology, and earth, space, and environmental sciences” (NRC, 2012, p. 11). On the other hand, the *Framework* presents the meaning of engineering focusing on the engineering design process: “Engineering is a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants” (NRC, 2012, p. 202). In this study, based on the definitions above, I describe that engineering is a systematic and iterative design process used to meet human needs within constraints, and science is a way of understanding the natural world.

Engineering design is similar to scientific inquiry in that they both involve systematic and iterative processes to solve problems. These reasoning processes include brainstorming, modeling, testing, and evaluation (NRC, 2009; 2012). However, the engineering design process reflects unique characteristics of engineering. Engineering design is conducted within specifications and constraints to meet the client’s needs. For example, engineers will typically consider cost and available materials, but scientists often put less emphasis on cost constraints or the practical purposes of their work when they are seeking an answer to the question (NRC, 2009; 2012). Another difference is an approach to the final solution. To find solutions, whereas engineers apply general principles to particular problems and specify their conditions for problem solving, scientists build theories to explain natural phenomena and try to generalize theories as a law such as Newton’s law. Basically, all these differences between scientific inquiry and engineering design come from the goals of each discipline. While the goal of science is to construct theories that provide explanations for the phenomena of the world, the goal of

Table 3

Characteristics of Scientific Inquiry and Engineering Design (NRC, 2009, p. 40)

Scientific Inquiry	Engineering (or Technological) Design
Demands of evidence	Purposeful
A blend of logic and imagination	Based on certain requirements
Explains and predicts	Systematic and iterative
Tries to identify and avoid bias	Creative
Not authoritarian	Many possible solutions

engineering is to design solutions to solve problems (NRC, 2009; 2012). Characteristics of engineering design and scientific inquiry are presented as shown in Table 3 (NRC, 2009, p. 40).

The Meaning of Science and Engineering Practices in the NGSS

The *Frameworks* (NRC, 2012) introduced “...practices that scientists employ as they investigate and build models and theories about the world and a key set of engineering practices that engineers use as they design and build systems” (p. 30). The *Framework* describes that they use the term “practices” instead of “skills” to emphasize that engaging in scientific inquiry requires both skill and knowledge. In other words, the ultimate goal of practices is to engage in “scientific inquiry.” Nonetheless, the *Framework* does not use the term “inquiry” and explains the reason for this as “the term inquiry, extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community” (NRC, 2012, p. 30). Therefore, part of the *Framework’s* intent “in articulating the practices is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires” (NRC, 2012, p. 30). Then, what is scientific inquiry?

Scientific Inquiry (SI)

Teaching students to participate in and learn from scientific inquiry (SI) has been a goal of science education for a long time (Bartos & Lederman, 2014; NRC, 2012; Osborne, 2014). Schwartz, Lederman, and Crawford (2004) asserted that “scientific inquiry refers to the methods and activities that lead to the development of scientific knowledge” (p. 612). However, as mentioned above, there is no consensus about the definition of scientific inquiry, and it has been perceived in at least three different ways (Lederman, Antink, & Bartos, 2012).

In a study by Lederman, Antink, and Bartos (2014), they described the meaning of scientific inquiry by distinguishing between nature of science (NOS) and scientific inquiry. NOS refers to “characteristics of scientific knowledge that are inherently derived from the manner in which it is produced, that is scientific inquiry” (p. 287). In other words, scientific inquiry refers to science processes, such as questioning, observing, measuring, and analyzing, including scientific reasoning and critical thinking for developing scientific knowledge.

Moreover, SI is considered a set of skills to be learned by students, a cognitive outcome that students are to achieve, and a teaching approach used to communicate scientific knowledge to students or to allow students to construct their own knowledge (Lederman et al., 2014). Although several scholars have defined scientific inquiry, the meaning of inquiry-based teaching in science seems ambiguous. Moreover, as shown in Table 4, the confusion gets worse when we compare the content standards for science as inquiry by the NRC, published in 1996, with the eight science and engineering practices in the *Frameworks* from 2012 (the order of the eight practices was rearranged to make comparisons easier between components). They both include almost the same content.

Table 4

A comparison of content standard for science as inquiry with scientific and engineering practices (NRC, 2000, p. 18; NRC, 2012, p. 42)

Content standard for science as inquiry: fundamental abilities necessary to do scientific inquiry (Grades 5-8)	Scientific and engineering practices
Identify questions that can be answered through scientific investigations	Asking questions (for science) and defining problems (for engineering)
Design and conduct a scientific investigation	Planning and carrying out investigations
Use appropriate tools and techniques to gather, analyze and interpret scientific data	Analyzing and interpreting data
Develop descriptions, explanations, predictions and models using evidence	Developing and using models
Think critically and logically to make the relationship between evidence and explanations	Engaging in argument from evidence
Recognize and analyze alternative explanations and predictions	Constructing explanations (for science) and designing solutions (for engineering)
Communicate scientific procedures and explanations	Obtaining, evaluating, and communicating information
Use mathematics in all aspects of scientific enquiry	Using mathematics and computational thinking

Osborne (2014) pointed out that many teachers consider that inquiry requires students to engage in practical activities, such as hands-on activities (see Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2008). Consequently, laboratory experiments are often felt to be required to verify phenomena rather than to help students develop their thinking abilities through the analysis of data. Moreover, as inquiry-based teaching is understood either as the doing of science or the learning of science, the concept of inquiry is poorly articulated. For these reasons, the eight scientific and engineering practices are pivotal in that they offer clear instructions of what students should learn and do even though the content is not very different from the content standard for science as inquiry. In addition, the *Frameworks* present several reasons for emphasizing these practices: helping students understand the crosscutting concepts and

disciplinary ideas, making knowledge meaningful, stimulating curiosity, capturing students' interest, motivating study, and recognizing scientists and engineers' work (NRC, 2012).

Difficulties with Teaching Integrated Lessons

Many teachers are reluctant to teach integrated STEM curricula due to their fear and lack of experience with integrated curricula (Cunningham & Carlson, 2014). This reluctance is often related to teacher sense of self-efficacy for teaching the particular subject matter content, which means "teachers' beliefs about their capabilities to produce a desired effect on student learning" (Stohlmann et al., 2012, p. 29). As a component of teachers' pedagogical content knowledge, teacher self-efficacy influences actual teaching practices (Park & Oliver, 2008b) and student achievement (Caprara, Barbaranelli, Steca, & Malone, 2006; Ross, 1995).

Since teachers' subject matter knowledge and pedagogical knowledge play a significant role in teacher efficacy (Stohlmann et al., 2012), teachers' lack of subject matter knowledge in integrated STEM education is a critical reason for this reluctance. Many elementary teachers had little confidence in teaching science due to their weak science knowledge (Lee et al., 2008; Sun & Strobel, 2014), and they were afraid of teaching engineering topics due to their lack of experience with engineering education (Liu, Carr, & Strobel, 2009).

In a similar manner, as secondary science teachers have strengths in their specific majors, it has been documented that significant difficulty can arise when called on to teach another science discipline (Stinson, Harkness, Meyer, & Stallworth, 2009). For example, middle school teachers who had subject backgrounds in mathematics, science, and technology were not confident in their implementation of the Project Lead the Way (PLTW) curriculum and exhibited more comfortable feelings with their teaching of familiar subject matter within the curriculum (Stohlmann et al., 2012). On the other hand, some teachers do not recognize engineering content

in their lessons due to their lack of content knowledge in engineering. For instance, high school chemistry teachers responded that they did not include engineering content in their classrooms even though they were using engineering approaches, such as student-led projects and lab activities (Boesdorfer & Staude, 2016).

Extensive teaching experience is connected with the teachers' reluctance with respect to their subject matter knowledge and pedagogical knowledge. Research has documented that many experienced teachers have little motivation to attempt a new teaching strategy or a new curriculum (Abrami, Poulsen, & Chambers, 2004; Donnelly & Sadler, 2009) because it appears that there are few rewards, considering the time and effort involved. The knowledge teachers possess is often acquired through experience, and therefore teaching strategies and practical knowledge are the results of exhaustive trial and error. Therefore, teachers believe their teaching strategies are the best they can do for successful student learning because they have experienced many difficulties and successes while developing their own practical knowledge (Guskey, 1989; van Driel et al., 2001). In other words, as teachers become comfortable with and established in their teaching practices as their teaching experience increases, they resist change. This resistance to change arises from their attitudes and beliefs as well as their subject matter knowledge and knowledge of how to successfully teach. Consequently, there is no reason for teachers to take a risk by changing their teaching strategies.

On the other hand, research has shown that, in general, novice teachers frequently do not have both adequate subject matter knowledge and pedagogical knowledge for teaching in their disciplines, much less in another subject (Lederman, Gess-Newsome, & Latz, 1994). However, related research has shown that novice teachers were more adaptable and had greater success when teaching a new curriculum than experienced teachers (Donnelly & Sadler, 2009). Other

scholarship in this area has shown that although prospective secondary mathematics and science teachers were concerned about their lack of content knowledge, instructional knowledge, and teaching experience, they successfully created integrated lessons connecting mathematics and science topics by collaborating with other teachers during their student teaching internships (Frykholm & Glason, 2005).

Lack of instructional knowledge, across the range of all concepts contained in this label, is another challenge to implementing integrated curricula (Frykholm & Glason, 2005; Sun & Strobel, 2014; Stohlmann et al., 2012). Whereas rich content knowledge is essential for teaching practices, novice teachers' content knowledge cannot be adequately enacted in instructional sessions without pedagogical content knowledge (Shulman, 1986). For instance, teachers had difficulties with time management for STEM curricula and guiding students in STEM activities (Stohlmann et al., 2012). The PLTW teachers in Stohlmann et al.'s (2012) research felt less comfortable with and little confidence in their pedagogical knowledge because they did not know what direction students would go in the lessons. Since the teachers used a student-centered approach, the students designed and developed their own ideas to make a Rube Goldberg machine. Therefore, when students asked questions about their machines, the teachers had difficulty answering the questions.

A study by Capobianco and Rupp (2014) also indicated the role of time management issues and a teacher-centered approach to teaching. These STEM teachers, who taught fifth and sixth grades, showed strength in planning for integrated engineering design-based lessons. While the teachers created well-organized lesson plans that incorporated engineering practices, they had difficulty implementing these practices with regard to time distribution of their lessons. The teachers usually spent considerable instructional time teaching introductory parts of the design

process such as problem identification and planning. However, their allocation of time did not allow enough time for student activities such as designing solutions, conducting practices, and discussing their results.

The researchers argued that the reasons for the inadequate time division were limited class time and a teacher-guided approach to teaching. Since the teachers employed a teacher-guided exploratory approach to engineering design-based science instruction, the students did not have opportunities to design and conduct engineering activities by themselves. If teachers instruct all processes of the activity instead of guiding students, the engineering practices are just different forms of teacher-centered lectures. Similar cases occur in inquiry-based teaching practices: “At its [inquiry practice] worst, the product is cookbook laboratory exercises where students simply follow a series of instructions to replicate the phenomenon” (Osborne, 2014, p. 178). In other words, teachers need both pedagogical knowledge and subject content knowledge for reducing the gap between planning and implementing the innovative curriculum (van Driel et al., 2001).

One interesting study indicated that secondary science teachers who had training in modeling instruction had more motivation and confidence when implementing the NGSS practices than others who did not have training experience with modeling (Hagg & Megowan, 2015). The teachers with training in modeling instruction displayed increased confidence in teaching the NGSS practices because they considered the NGSS as being aligned with modeling instruction. In other words, the teachers had instructional strategies and experience with modeling, and these features supported the teachers’ confidence in teaching the practices. The researchers argued that the foundation of the NGSS practices is a research-based pedagogy representing modeling instruction. Modeling instruction integrates a student-centered teaching

approach with a model-centered curriculum that encourages students to develop skills, such as data analysis or quantitative estimation.

Teachers also encounter practical barriers to the implementation of the integrated curriculum such as class schedules, lack of experimental materials, or space (Trygstad, Smith, Banilower, & Nelson, 2013; Hagg & Megowan, 2015). Class schedules can be a barrier for implementing STEM curricula because integrated lessons usually require more time for implementation as compared to regular lessons. These kinds of obstacles cannot be overcome without the assistance of schools and school districts.

School Environment/Supportive Atmosphere

The school environment is another factor that influences teachers' practices during implementation of a new curriculum (Woodbury & Gess-Newsome, 2002). Even when teachers agree with the importance of the STEM curricula, it is difficult to enact the new curricula and change traditional teaching and learning approaches in real classrooms without the school district's support. Whereas a favorable atmosphere of a school encourages teachers to incorporate the new curricula (Anderson & Helms, 2001), in a less supportive environment, where for instance the goals are focused on standardized testing, new curricula that does not align with the standards on which the assessments are based lead to teachers participating less in implementing the curriculum (Sutherland et al., 2004). In another study which examined similar issues, elementary teachers talked about the lack of support from the administration as a challenge to engineering integration into elementary classrooms (Sun & Strobel, 2014). These researchers argued that teaching engineering depends on the school environment because teachers feel pressured to teach to the test. However, engineering is not included on the standardized tests, and it is not state mandated.

Given these psychological and physical/environmental barriers, teachers need both emotional and practical support to be motivated and confident for the successful adoption of integrated STEM curricula. Exposure to professional development with various engineering activities and teaching experiences with integrated lessons in the context of real classrooms diminished teachers' anxiety about STEM curricula (Frykholm & Glason, 2005; Sun & Strobel, 2014).

Stohlmann et al. (2012) suggested a support, teaching, efficacy, and materials (s.t.e.m.) model for teaching STEM curricula, which included: partnership with a university or a school, professional development (PD) programs, and teacher collaboration (support); planning and teaching experience with integrated lessons (teaching); content knowledge, PCK, and commitment for positive self-efficacy (efficacy); and technology resources, room space, and activity materials (material).

Even though most studies, as discussed above, emphasized the importance of appropriate PD programs for teaching STEM curricula, research on PD for engineering integration is emerging (Daugherty & Custer, 2012). Daugherty and Custer (2012) examined five representative engineering PD programs, which included *Engineering the Future* (EtF), *Project Lead the Way* (PLTW), *the Mathematics Across the Middle School MST Curriculum Project* (MSTP), *The Infinity Project*, and *Increasing Student Participation, Interest, and Recruitment in Engineering and Science* (INSPIRES) in terms of content and pedagogy at the secondary school level. This study indicated that the PD programs concentrated on providing experience with engineering activities and learning engineering-related tools with a focus on engineering the design process rather than content. For example, PLTW program participants spent considerable time in learning computer-aided design (CAD) software, and the LabVIEW software was

essential in *The Infinity Project*. Another study conducted a program that was designed to provide experiences with engineering design processes for high school STEM teachers (Chin, Zeid, Duggan, & Kamarthi, 2011). This program consisted of engineering design project planning, investigations, data collection, and analysis and dealt with the process for the goal of engineering design. The authors contended that PD programs should emphasize engineering design and should be taught with appropriate tools such as computer software and resources for teaching engineering design processes.

Other research on PD has shown that specific content (subject matter knowledge) should be included in PD for obtaining practical effects from the PD programs (Guskey, 2002; Guzey, Tank, Wang, Roehrig, & Moore, 2014). If science teachers consider engineering as an addition to the science curriculum, it will be difficult to integrate engineering into real science classrooms (Guzey et al., 2014; Yager & Tamir, 1993). Therefore, PD programs for engineering integration should facilitate teachers' learning about the ways of teaching science knowledge using engineering, not teaching engineering as additional content. Moreover, development of engineering design activities for investigating life science concepts is needed. Most engineering PD programs were designed to integrate physical science concepts, and even participating teachers also created lesson plans that included physical science concepts (Daugherty & Custer, 2012; Guzey et al., 2014).

Furthermore, empirical evidence that shows substantial improvement in students' achievement can motivate teachers when implementing new curricula. Guskey (2002) argued that, after confirming students' more positive outcomes which are associated with the implementation of new curriculum, teachers are likely to change their attitudes and perceptions. Yager and Tamir (1993) suggested that convincing teachers that a revision of the curricula in

which science-technology and society (STS) is the overriding description will be more effective when teachers are shown that this new curriculum is not an “add-on” but rather a different approach.

Ill-Structured Problem-Solving Ability

A Framework for K-12 Science Education (National Research Council [NRC], 2012) stated that “Engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. A societal problem such as reducing the nation’s dependence on fossil fuels may engender a variety of engineering problems, such as designing more efficient transportation systems” (p. 50). One important role of engineering in STEM education is the introduction of real-world problems to be solved.

When it comes to a vital skill for students in the twenty-first century, having the ability to solve problems is essential. In order to support students in developing problem-solving abilities, we have to define what a problem is first. Jonassen (2000) presents two significant attributes of a problem: an unknown entity in a situation, and a social, cultural, or intellectual value of the unknown. In other words, if a problem is derived from a gap between a goal and a current state, the problem has a meaning only when it is perceived as an unknown. As different kinds of problems require different cognitive processes, different types of problems are presented based on their characteristics: logical, algorithmic, story, rule-using, decision making, troubleshooting, diagnosis-solution, design, and dilemma problems (Jonassen, 2000).

Jonassen (2000) distinguished between well-structured problems and ill-structured problems. Well-structured problems present all elements of the problem to the learners, require the application of a limited number of regular and well-structured rules, possess correct answers and have knowable, comprehensible solutions (p. 68). On the other hand, ill-structured problems

are situated in and emerge from a particular context that we meet in everyday life. Ill-structured problems have multiple goals and multiple solutions so that the problems can be solved in many different ways, and multiple criteria should be considered for evaluating solutions (Jonassen, 2000; Jonassen et al., 2006). For instance, engineers have multiple goals, including the function of the product and low cost. They reconcile the two goals to meet the client's demands, and there is no correct answer in this case. Jonassen, Strobel, and Lee (2006) argued that problems in real life are largely ill-structured and learning well-structured problems in classrooms does not easily transfer to ill-structured workplace problems.

Problem-Based Learning and Project-Based Learning

Project-based learning and problem-based learning have many similarities, and people are likely to be confused between the two concepts. Both approaches involve student-centered learning and help students to develop problem solving and higher order thinking abilities.

In this study, the participating teachers adopted project-based learning as a method of implementing integrated STEM lessons. To better understand the teachers' implementation, in this section, I discuss similarities and differences between project-based learning and problem-based learning.

Problem-based learning was originally developed for overcoming difficulties for preparing students in medical education for what is now labeled as ill-structured problems (Barrows, 1996; Hung, Jonassen, & Liu, 2008). Research had shown that the medical students had a disappointing clinical performance which was attributed to their approach to learning, characterized mainly by memorization of knowledge without consideration of practical applications. In order to overcome these difficulties, problem-based learning focused on developing independent learning skills and problem-solving abilities. Problem-based learning

has the following characteristics: Students learn organized content and skills through problems, it is a student-centered learning approach, which is independent and self-reflective; and teachers act as facilitators (Hung et al., 2008).

However, there are different research results concerning the impact of problem-based learning on students' academic achievement. Several studies described that when students engaged in problem-based learning curricula they showed no significant difference or underperformed on assessments of content knowledge acquisition compared to students who were taught using a traditional teaching method (Gallagher & Stepien, 1996; Mergendoller, Maxwell, & Bellisimo, 2000; Perrenet, Bouhuijs, & Smits, 2000). Moreover, while the medical knowledge has an encyclopedic structure, engineering, mathematics, and physics are best ascertained in hierarchical structures of knowledge (Mills & Treagust, 2003). This means that concepts must be learned in a certain order, and missed topics are critical obstacles for learning later concepts.

Compared with problem-based learning, project-based learning emphasizes developing teamwork and communication skills through group work. Mills and Treagust (2003) presented differences between the two approaches: Project-based learning takes a longer time and focuses on the application of knowledge while problem-based learning shifts its focus to the acquisition of knowledge. Heywood (2005) also suggested that project-based learning is concerned with the development of cognitive and practical skills, whereas problem-based learning is concerned with the acquisition of content.

Projects are often used as vehicles for integrating the disciplines. In other words, project-based teaching is seen as a powerful method for helping students integrate their previously acquired knowledge through practical means (Bell, 2010; Heywood, 2005; Mills & Treagust,

2003). An important benefit of project work is that students can develop skills that cannot be assessed through traditional written examinations such as planning or synthesizing abilities. Also, project work often implies a change in teacher-student relationships from teacher-centered to student-centered learning.

Krajcik and Blumenfeld (2006) presented five characteristics of project-based learning. They are: learning with a driving question, learning through situated inquiry with processes of problem solving, engaging in collaboration, using learning technology, and creating artifacts. The authors asserted that project-based learning supports students to acquire a deep understanding of science knowledge by actively constructing knowledge, not acquisition of superficial understanding.

In addition, Bell (2010) advocated project-based learning in that students do a self-evaluation of both their learning processes and social interactions. Also, according to this research, project-based learning provides intrinsic motivation to learn, developing creativity, real-world connections, and critical thinking skills.

Assessment of Student Achievement through Integrated Learning

Assessment is an essential part of education for both teachers and students: “The assessment is the curriculum, as far as the students are concerned. They will learn what they think they will be assessed on, not what is in the curriculum, or even on what has been covered in class” (Biggs, 2003, p. 3). Assessment of student learning is key to determining the success of an innovative curriculum.

Many scholars have discussed the assessment issues of innovative teaching strategies (Bell, 2015; Brophy et al., 2005; Hung et al., 2008; Mills & Treagust, 2003). These researchers argue that anticipated student outcomes from problem-based or project-based learning, such as

higher-level thinking skills, motivation to learn, teamwork, or communication skills, cannot be assessed properly by using traditional assessment methods.

On the other hand, school administrators need clear and unequivocal evidence of student achievement that show the effects of innovative strategies. Scholars have acknowledged that teachers have difficulty assessing student outcomes when they are implementing a new instructional method.

Yager and Tamir (1993) argued that one reason for the disappointing outcomes of the curriculum reforms in the 1960s was inappropriate assessment areas of student learning. They asserted that assessment on traditional performance domains, such as content knowledge, could not appropriately measure the outcomes of the innovative approaches resulting from higher level objectives: “The goals and activities of a curriculum should be the primary criteria for selecting and developing areas for assessment” (p. 655).

Yager and Tamir (1993) categorized five goals for assessment of the curriculum in terms of general domains. They labeled these domains as Concepts, Processes, Applications, Creativity, and Attitude and advocated for assessment of student outcomes in each domain. In contrast to the curriculum reforms of the 1960s, the authors designed domains for assessment to examine the impact of the Science-Technology-Society (STS) approach. In a similar manner, it is essential to clarify assessment domains that show effectiveness and improvement in students’ abilities with STEM curricula.

In the study reported here, the five domains described by Yager and Tamir (1993) will be adopted as a component of the theoretical framework for assessment. More specifically, when teachers design assessments to evaluate these five domains, the Structure of the Observed Learning Outcome (SOLO) Taxonomy (Biggs & Collis, 1982) or Bloom’s taxonomy

(Krathwohl, 2002) are applicable for promoting the high-level thinking abilities of students. In order to analyze thinking abilities, learning outcomes are categorized into five levels – prestructural, unistructural, multistructural, relational, and the extended abstract – based on the quality and complexity of student outcomes.

If the analysis of students’ written responses on an exam indicates that they understand only one or few aspects of the task, their learning outcome is classified into the unistructural level. If students’ written responses show that they understand several aspects but cannot make a relationship between these aspects, then the learning outcome is considered to be at the multistructural level. If the analysis shows that students can integrate parts into a whole structure, the learning outcome is considered to be at the relational level. Finally, the learning outcome is considered to be at the extended abstract level if students can generalize untaught applications. As shown in Table 5, the authors presented typical verbs that indicate levels of understanding. For example, if students ‘identify’ tasks or mention ‘names’ in their responses, the learning outcomes are classified into the unistructural level. If students ‘analyze,’ ‘apply,’ or ‘explain causes,’ then their outcomes are considered to be at the relational level. Minogue and Jones (2009) examined middle school students’ understandings of cell concepts. They used the SOLO

Table 5
Sample verbs indicating levels of understanding with the SOLO Taxonomy (retrieved from <http://www.johnbiggs.com.au/academic/solo-taxonomy>).

Fail Incompetent Misses point	Identify Name Follow simple procedures	Combine Describe Enumerate Perform serial skills List	Analyze Apply Argue Compare/contrast Criticize Explain causes Relate Justify	Create Formulate Generate Hypothesize Reflect Theorize
Prestructural	Unistructural	Multistructural	Relational	Extended Abstract

taxonomy to code students' written responses and categorized these responses according to the levels of the SOLO Taxonomy.

Hodges and Harvey (2003) analyzed students' answers given on their course exams to identify student learning difficulties and progress in understanding particular content knowledge using the Structured Observation of Learning Outcomes (SOLO) Taxonomy (Biggs & Collis, 1982). They argued that educators can use the SOLO taxonomy for assessing students' conceptual understanding and adapting their teaching goals and strategies accordingly. In this way, the SOLO taxonomy can be used as an approach for assessing student thinking abilities.

Another framework that teachers can refer to in assessment is Bloom's taxonomy (Krathwohl, 2002). The author revised Bloom's taxonomy in two dimensions: The Knowledge Dimension and the Cognitive Process Dimension. The Knowledge Dimension includes four categories – Factual Knowledge, Conceptual Knowledge, Procedural Knowledge, and Metacognitive Knowledge – and the Cognitive Process Dimension includes six categories – Remember, Understand, Apply, Analyze, Evaluate, and Create. The author suggested the two-dimensional Taxonomy Table that can be used in designing learning objectives as well as in creating assessments. The Taxonomy Table helps teachers recognize what they intend students to learn and how well students accomplish those objectives.

Zheng, Lawhorn, Lumley, and Freeman (2008) showed an application of Bloom's Taxonomy as an assessment tool for evaluating test questions. They argued that multiple-choice questions can be used to assess high-level thinking abilities by analyzing the Medical College Admission Test (MCAT) and the biology Graduate Record Examination (GRE) based on Bloom's Taxonomy. The research results showed that the exam questions trigger students' high-level thinking abilities because many of the questions are placed in the application and analysis

levels of Bloom's taxonomy. The authors asserted that their assessment is credible because these tests are nationally standardized exams.

To achieve students' anticipated learning outcomes, appropriate assessment that demonstrates the strengths of a new teaching method is essential. In other words, it is clear that if there are no evaluation results that show the potential for student achievement, it is difficult to assure teachers of the value of innovative instructional strategies. Therefore, it is essential to provide specific ways, such as the SOLO Taxonomy or Bloom's Taxonomy, to assess student outcomes that are direct results of the implementation of new teaching and learning approaches.

In order to help K-12 students develop critical abilities for the twenty-first century, such as creativity, communication skills, and problem-solving abilities, design-based learning and project-based learning are recommended. Moreover, integration of engineering content within science curricula is meaningful to encourage underrepresented students' engagement in their lessons. It is also helpful for understanding difficult scientific concepts and increasing motivation to learn by connecting with real-life contexts. Finally, appropriate assessment methods that show student outcomes derived from innovative instructional approaches are essential for the success of new teaching strategies.

Pedagogical Content Knowledge (PCK)

As Shulman (1986) asked in his article, "How does the teacher prepare to teach something never previously learned? How does learning for teaching occur?" (p. 8). In determining how to encourage science teachers to implement the new instructional approaches, including integrated STEM curricula, it is important to investigate types of teacher knowledge related to their teaching practices. Shulman (1987) perceived PCK as consisting of two key elements: knowledge of representations of subject matter and knowledge of student

understanding regarding the subject matter. Grossman (1990) elaborated on Shulman's work and presented four components of PCK: knowledge of strategies and representations for teaching particular topics, knowledge of students' understanding of the subjects, knowledge of the purposes for teaching a subject, and knowledge of curriculum.

In addition to Grossman's conceptualization, Park and Oliver (2008a, 2008b) included knowledge of assessment and teacher efficacy. Their hexagon model represents science teachers' PCK as six components: orientations to teaching science, knowledge of students' understanding in science, knowledge of science curriculum, knowledge of instructional strategies for teaching science, knowledge of assessment of student learning, and teacher efficacy. For this study, I adapt this hexagon model of PCK by Park and Oliver (2008b) for investigating secondary science teachers' PCK development.

A component, orientations to teaching science, refers to teachers' beliefs about the purposes and goals for teaching science. Teachers' beliefs about the goals for teaching science conduct as a "conceptual map" that influences the teachers' overall instruction such as learning objectives or assessment methods (Magnusson, Krajcik, & Borko, 1999). To better understand teachers' orientations, I adopted the nine orientations to teaching science by Magnusson, Krajcik, and Borko (1999): process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry. As shown in Table 6, they identified the goals and instructional characteristics based on the nine orientations to teaching science.

Knowledge of students' understanding in science includes knowledge of students' understanding of a subject, such as conceptions, misconceptions, or learning difficulties in specific topics. Also, this knowledge includes understanding of students' diversity such as

Table 6

The Goals and Characteristics of Instruction Based on Different Orientations to Teaching Science (Magnusson, Krajcik, & Borko, 1999)

Orientation	Goals of Teaching Science	Characteristics of Instruction
Process	Help students develop the “science process skills”	Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Represent a particular body of knowledge	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.
Didactic	Transmit the facts of science	The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.
Conceptual Change	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions	Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.
Activity-driven	Have students be active with materials; “hands-on”	Students participate in “hands-on” activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	Provide opportunities for students on their own to discover targeted science concepts	Student-centered. Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project-based Science	Involve students in investigating solutions to authentic problems	Project-centered. Teacher and student activity centers around a “driving” question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts (products) that reflect their emerging understandings.
Inquiry	Represent science as inquiry	Investigation-centered. The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.
Guided Inquiry	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science	Learning community-centered. The teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students’ efforts to use the material and intellectual tools of science, toward their independent use of them.

different learning approaches or development levels. For example, teachers differentiate their teaching based on the students' learning abilities and developmental levels.

Knowledge of science curriculum refers to teachers' knowledge about curriculum materials for teaching science. This curricula knowledge includes knowledge of goals and objectives in the subject teachers teach and knowledge of specific curricula programs in science such as Great Explorations in Math and Science (GEMS) (Magnusson et al., 1999).

Knowledge of instructional strategies is comprised of general approaches to instruction, such as inquiry-based teaching and specific strategies for teaching science topics. Magnusson et al. (1999) described two categories: knowledge of subject-specific strategies and knowledge of topic-specific strategies. Knowledge of subject-specific strategies means general teaching approaches based on the orientations to science teaching. For instance, the learning cycle strategy which consists of exploration, term introduction, and concept application (Karplus & Their, 1967) has been used for conceptual change or discovery. Knowledge of topic-specific strategies refers to teachers' knowledge of representations and activities according to the specific topics (Magnusson et al., 1999). Teachers use different representations such as illustrations, models or analogies and employ different activities such as experiments or problem solving based on the topics.

As a component of PCK, teachers' knowledge of assessment includes knowledge of student learning as well as knowledge of assessment methods (Tamir, 1988; Park & Oliver, 2008a, 2008b; Sun & Strobel, 2014). Knowledge of assessment methods refers to teachers' knowledge of methods to assess the student achievement in the specific area. For example, students' reasoning abilities can be assessed by written tests while their learning process or

creativity can be assessed through portfolios or journals (e.g., Kang, Thompson, & Windschitl, 2014).

A few studies have shown that when teachers encountered assessment difficulties due to unfamiliar subject matter, they employed different assessment methods for two purposes: to know their students' understanding and learning needs and to encourage and improve their students' learning (Park & Oliver, 2008a; Sun & Strobel, 2014). The elementary teachers who participated in professional development programs for practicing engineering teaching had difficulties assessing students' engineering learning using traditional tools such as rubrics or questions (Sun & Stroble, 2014). After trying traditional/formal assessment methods, the teachers employed different informal assessment methods in their engineering teaching such as questioning, journals, observations, or flow maps.

The teachers' usage of the different assessment methods depended on the assessment purposes. For example, some teachers asked their students to create their own criteria for assessing their engineering products in order to encourage their students to focus on the learning goals. Similarly, National Board Certification (NBC) candidate science teachers used multiple assessment methods to gauge student understanding, learning progress, and student learning styles (Park & Oliver, 2008a). The high school teachers came to be aware of the importance of diagnostic assessment and employed diverse assessments such as rubrics, oral and written feedback, or graphic organizers to enhance student learning. In either case, the teachers developed knowledge of assessment through teaching practices within the specific teaching context.

On the other hand, the development of appropriate assessment methods is an important issue in STEM education. A project, Engineering is Elementary (EiE), developed assessment

methods to measure students' understanding of engineering and technology (Cunningham, Lachapelle, & Lindgren-Streicher, 2005). The assessment consisted of open-ended questions, including images of people at work, that asks what engineers do and what technology is. This study revealed elementary students' lack of understanding about engineering, such as perception of it being male-oriented work. Other research also has been focused on assessing students' perceptions about the STEM disciplines or its impact on science knowledge (Apedoe et al., 2008; Brophy et al., 2008; Cunningham et al., 2005; Mehalik et al., 2008; Sadler et al., 2000). Therefore, more in-depth research on appropriate assessment and methods in order to understand teachers' knowledge is necessary for successful implementation of the STEM curricula.

Lastly, teacher efficacy refers to teachers' beliefs about their capabilities to execute expected student achievement (Park & Oliver, 2008b; Stohlmann et al., 2012). Teacher efficacy influenced teachers' actual teaching and curriculum design. For instance, elementary teachers were reluctant to include engineering content in their curriculum because they had little confidence in teaching science and engineering.

Summary

In this chapter, I examined definitions of STEM education and categorized four approaches for STEM education. I employed the specialized approach, which means that STEM curriculum includes two or more subjects of STEM subjects, for this study. I also presented the meaning of the engineering design process and compared characteristics between science and engineering. Furthermore, I discussed assessment methods of student achievement through integrated STEM lessons. Finally, I explored teachers' pedagogical content knowledge (PCK) as a framework to analyze the participating teachers' beliefs and knowledge.

CHAPTER 3

METHODOLOGY

Qualitative research methodology, specifically a multiple case study, was used for the data collection and analysis in this study. Multiple case study methodology is useful for investigating and understanding a program, process, event, or individuals in a real-life context. Through close description and interpretation of events, case study is a powerful means to gain insights and in-depth understanding (Patton, 2015; Simons, 2009). Moreover, multiple case studies allow researchers to study similarities and differences through comparative analysis: “Comparisons are information-rich in that they provide insights into both the unique attributes and the common characteristics of the selected cases” (Patton, 2015, p. 282).

This study investigated middle school science teachers’ perspectives on STEM curricula and their practices in the light of Park and Oliver’s (2008) PCK model. Therefore, given the purpose of the study and research questions, multiple case study methodology is appropriate for this research because “it can determine the factors that were critical in the implementation of a program or policy and analyse patterns and links between them” (Simons, 2009, p. 18).

Data Collection

This study was conducted at Norton Middle School (NMS, pseudonym) in a suburban area in Georgia during the 2017-2018 academic year. This middle school, with an enrollment of approximately 2,200 students, was in the early stages of developing an integrated STEM curriculum. The sixth-grade earth science teachers at NMS had planned and implemented project-based learning (PBL) lessons as a model of integrated lessons. Based on the results of the

PBL lessons, they had a plan to expand integrated STEM lessons to the whole curricula of earth science and to the seventh (life science) and eight (physical science) grades. In this context, the teachers at NMS had many opportunities and challenges when designing and implementing the STEM curriculum.

I observed the three participating sixth grade earth science teachers as they taught PBL and ordinary lessons. Before and after each classroom observation, I interviewed the teachers about the day's lessons. Two individual interviews were conducted for approximately 1 hour in the beginning and at the end of the study. The semi-structured interviews were audio-recorded and transcribed for a rigorous analysis of the data. Field notes were made to record discussions with students and characteristics of the participants' teaching.

I also joined the curriculum meetings with the sixth grade science teachers. The teachers discussed their challenges in teaching PBL lessons and shared ideas for overcoming the obstacles. Also, they planned the next lesson at the meeting and designed assessments to measure students' achievement. I did not express any opinions of their lesson plans or assessments or make any suggestions because I did not want to influence their teaching, but rather I maintained my role as a researcher. Moreover, I participated in three STEM conferences where students presented their STEM products and research results. Other data for this study included students' work artifacts, teachers' instructional materials, field notes, presentations, and worksheets for triangulation in the analysis (Glaser & Strauss, 1967).

Research Site

Norton Middle School (NMS) was preparing to teach integrated STEM curricula. As a first step, the sixth-grade science teachers taught project-based learning (PBL) lessons as a method of implementing the integrated STEM curricula. For the 2016-2017 school year, 2,176

students were enrolled at this middle school. Norton Middle School (NMS) has a diverse student body: Among the students, 29% were African American, 29% were Hispanic or Latino, 24% were White, 13% were Asian, and 5% were multiracial. Fourteen percent of students were in special education, and 8% were in English for Speakers of Other Languages (ESOL). Half of the students (50%) received free/reduced lunch. When considering Georgia's College and Career Ready Performance Index (CCRPI), the achievement level of NMS with its particular degree of student poverty met the expected performance in 2017 (Achieve, 2017).

Georgia Milestones is the assessment system measuring students' achievement outlined in the state-adopted content standards. There are four categories of achievement: Distinguished Learner, Proficient Learner, Developing Learner, and Beginning Learner. The percentage of students who achieved at the level of Proficient Learner or higher in mathematics in the sixth grade at NMS in 2017 was 54.1%. This was higher than the county's average percentage (53.3%) and Georgia's average percentage (38.2%). On the other hand, in English language arts and science, the percentages of students who achieved the high level were 48.0% and 45.9%. They were lower than the county's average percentages (51.3% and 40.3%), but they were higher than the state's average percentage of the students (40.3% and 37.8%). Based on the statistical records, student achievement at NMS was considered average. Also, NMS cooperated with its cluster schools, one high school and four elementary schools, to promote integrated STEM lessons (Achieve, 2017). In particular, its cluster high school had been offering to a small portion of their student body a program called cSTEM which stands for STEM with emphasis on communication. This program has been in place for approximately 10 years and was an important referent for NMS's curricular goals and programs.

Participants of the Study

The participants in this study were three in-service middle school science teachers who had been teaching earth science but at the time of this study were being called on to teach STEM curricula. The assistant principal of the school, who was instrumental and enthusiastic about transitioning to the STEM curricula, also actively participated in this study. I investigated both the administrator's and the science teachers' perspectives because collectively they can present different ideas for overcoming difficulties in teaching integrated lessons.

Initially, I visited the school and explained the purpose of the study to encourage teachers to participate. Volunteers were asked to participate in a preliminary survey for selecting participants. As shown in Table 7, the survey questions were designed to collect information about the participants' backgrounds, experience with STEM activities, and perspectives on science and engineering practices in the NGSS. From a total of 15 volunteers, three teachers were selected as participants for this study based on an examination of the results of the preliminary survey, specifically information regarding their backgrounds, teaching experience, and perspectives on the eight NGSS practices. They were experienced teachers who had been teaching sixth grade earth science. All the names of the participants, including the administrator, that were used in this study are pseudonyms (Dan, Emily, Chris, and James).

The backgrounds of the participants, including work experience before becoming a teacher, were investigated in order to know their STEM-related experiences. As explained by Kim, Oliver, and Kim (2019), preservice science teachers' STEM-related experiences influence their perspectives on integrated STEM lessons. In their research, the preservice science teachers showed different degrees of confidence and reluctance in teaching integrated lessons including engineering content based on their engineering-related experiences and knowledge. Although the preservice science teachers did not have previous experience in teaching engineering content,

Table 7

Preliminary Survey Questions for the Selection of Participants

Preliminary Survey Questions
1. How long and what subject(s) have you been teaching? If you have taught different subjects, please describe each subject and the years in which you taught them.
2. What was your undergraduate major? If you have any other degrees, please list all of your degrees and majors.
3. If you had work experience before becoming a teacher, please describe your job and what kinds of tasks you did at this job.
4. Have you had experience doing car repair, home repair/construction, gardening, or similar things in your life? If so, please describe these experiences briefly (e.g., When I was an undergraduate student, I repaired a radio on my own).
5. On a scale from 1 to 5, how difficult would it be for students to master the eight science and engineering practices in the NGSS? Please explain why you think specific practices are difficult/easy to master. (1 indicates that it would be easy and 5 indicates it would be difficult). <ol style="list-style-type: none"> 1) Asking questions (for science) and defining problems (for engineering) 2) Developing and using models 3) Planning and carrying out investigations 4) Analyzing and interpreting data 5) Using mathematics and computational thinking 6) Constructing explanations (for science) and designing solutions (for engineering) 7) Engaging in argument from evidence 8) Obtaining, evaluating, and communicating information
6. On a scale from 1 to 5, how difficult would it be for teachers to master the eight science and engineering practices in the NGSS in your opinion in order to be able to effectively teach them? Please explain why you think specific practices are difficult/easy to master. (1 indicates that it would be easy and 5 indicates it would be difficult). <ol style="list-style-type: none"> 1) Asking questions (for science) and defining problems (for engineering) 2) Developing and using models 3) Planning and carrying out investigations 4) Analyzing and interpreting data 5) Using mathematics and computational thinking 6) Constructing explanations (for science) and designing solutions (for engineering) 7) Engaging in argument from evidence 8) Obtaining, evaluating, and communicating information

those who had prior experience with engineering had an interest in developing integrated lessons, while others who had not encountered engineering content expressed fear about teaching engineering content.

Backgrounds of the participants in this study are presented in Table 8. Detailed backgrounds of the participants follow the table.

Dan. Dan received his bachelor’s degree in physics, and prior to teaching science, he had some other work experience as a Deputy Sheriff, as well as working in customer service and serving in the military. Dan is an experienced teacher who, in 2017, had been teaching earth and physical science for 28 years. He had taught eight grade physical science for 9 years and had been teaching sixth grade earth science for 19 years. Although he had been teaching only gifted students throughout most of his teaching years, during the academic year when this research was conducted (2017-2018), he was teaching two gifted classes and two grade-level classes.

Emily. In fall 2017, Emily had been teaching for 7 years. She majored in secondary education with a focus on mathematics and science during her undergraduate study and earned a master’s degree in curriculum and instruction focusing on assessments in July 2017. Prior to teaching in public school, her only work experience was teaching in an after-school program at a

Table 8

Backgrounds of Participants

Name (Pseudonym)	Major	Teaching Subject	Teaching Years	Gender	Terminal Degree
Dan	Physics	Earth and Physical Science	28	Male	B.S.
Emily	Middle School Education	Earth Science and Mathematics	7	Female	M.S.
Chris	Special Education	Earth Science and Special Education	40 (3 years as a principal)	Male	Ed.D.
James	Science Education	Biology	14 (6 years as an assistant principal)	Male	Ed.D.

church when she was in college. She started teaching in special education in 2011 and taught students with disabilities and emotional behavior disorders. Then, Emily taught general education and earth science for 3 years. In the 2017-2018 school year when this study was conducted, she was teaching both mathematics and earth science. She had no experience teaching integrated STEM classes. One interesting thing is that Dan was her earth science teacher when she was in middle school, and she really liked, and often referenced, Dan's style and practice of teaching.

Chris. As an undergraduate, Chris majored in special education with emphasis on kindergarten through 12th grade. He earned a master's degree in guidance counseling and a doctorate in school administration and leadership with emphasis on principals' decision making. His prior work experience included working for about 10 years in a grocery store owned by his father and then working at a steel mill for 2 years. In fall 2017, when he participated in this study, Chris had been teaching for a total of 40 years. He had 20 years of experience teaching in an elementary school and then taught special education in a high school for 2 years. He had also been the principal of a Catholic elementary school for 3 years. After moving to the middle school where this research was conducted, he taught special education and began teaching science in small-group classes. He had taught seventh-grade life science for special education for 11 years before transferring to sixth grade earth science. He became a general science teacher in 2015, and it was his second-year teaching in a general education setting at the time of the study. It was his last year of teaching, as he was planning to retire at the conclusion of the academic year in spring 2018.

James. James majored in environmental health science as an undergraduate and science education for his master's degree. He completed an educational specialist degree focusing on

educational leadership and administration and earned his Doctor of Education (Ed.D.) in Educational Leadership and Administration. He had taught life science for 8 years in a middle school and a high school before becoming the assistant principal at Norton Middle School (NMS) in 2013. At the time of this study, as the assistant principal at NMS, James was the leader of the science department for all grades, sixth to eighth, at NMS. He participated in curriculum design meetings and encouraged science teachers to teach integrated STEM lessons. He provided opportunities for teachers to have experiences in STEM, such as STEM conferences and professional development opportunities (e.g., meeting with an assistant principal from a STEM school and a STEM specialist). He had a strong interest in changing the science curricula from the traditional single-subject teaching to the innovative integrated STEM curricula.

In general, because secondary science teachers typically have a primary subject matter specialization, teaching different subjects can be a challenge for them (Stinson et al., 2009). Moreover, teachers' pedagogical content knowledge (PCK) should be examined with the specific subjects or topics in a specific context (Grossmon, 1990), as a depth of subject matter knowledge and teaching experience are influential factors for developing PCK. Therefore, secondary science teachers who have relatively more formal preparation in a specific subject matter knowledge field and teaching experience are more appropriate as participants than early career teachers or prospective teachers.

Semi-Structured Interviews

This study involved 5-minute pre-and post-observation interviews with each participant before and after his or her teaching. As shown in Table 9, I planned for the collection of evidence that was needed to answer the research questions and listed possible data sources for obtaining the evidence. While the pre-interviews consisted of questions about teachers' general ideas using

Table 9

Necessary Evidence to Answer the Research Questions and Ways of Collecting this Data

Research Questions	Needed Data/Evidence for Answering the Research Questions	Ways to Collect the Data/ Possible Data Sources	Sample Interview Questions
<p>What do middle school science teachers perceive as benefits of and challenges to implementation?</p>	<p>Benefits of the implementation of STEM curricula</p>	<ul style="list-style-type: none"> • Interviews before and after teaching STEM curricula • Observations • Lesson plans • Student work samples • Field notes 	<p>Pre-interview</p> <ul style="list-style-type: none"> -What do you think are some benefits of STEM education? (for the first interview) -What will the students be able to learn through today's lesson? <p>Post-interview</p> <ul style="list-style-type: none"> -How was student learning/performance different with the STEM curriculum? -What did the students learn through the lesson? -What abilities did students develop through the lesson?
	<p>Challenges to implementing STEM curricula</p>	<ul style="list-style-type: none"> • Interviews before and after teaching STEM curricula • Observation • Lesson plans • Student work samples • Field notes 	<p>Pre-interview</p> <ul style="list-style-type: none"> -What do you think are some challenges/drawbacks of STEM education? (for the first interview) <p>Post-interview</p> <ul style="list-style-type: none"> -How would you change the lesson if you were to teach the same class again? -What parts/activities of the lesson would it be difficult for students to learn/conduct? -How would you help students who have difficulties with your lesson? -What instructional challenges did you have in your teaching of the topic today?
<p>What influences on the components</p>	<p>Orientations to teaching science/STEM lessons</p>	<ul style="list-style-type: none"> • Interviews • Observations • Lesson plans • Student work samples 	<ul style="list-style-type: none"> -What are your goals for teaching a class based on the STEM curriculum? -What do you expect students to learn from your lesson?

of teachers' pedagogical content knowledge (PCK) can be determined when middle school science teachers implement STEM curricula?		<ul style="list-style-type: none"> • Field notes 	
	Knowledge of assessment of student learning	<ul style="list-style-type: none"> • Interviews • Observations • Lesson plans • Student work samples • Field notes • Gateway results 	<p>-How do you plan to assess student outcomes?</p> <p>-Are your assessment methods in STEM different from those in ordinary science classrooms?</p> <p>-If so, how is assessment different with the STEM curriculum?</p> <p>-How do you recognize if students understand the content/concepts?</p>
	Knowledge of instructional strategies for teaching science/STEM lessons	<ul style="list-style-type: none"> • Interviews • Observations • Lesson plans • Student work samples • Field notes 	<p>-Are your instructional strategies in STEM different from those in ordinary science classrooms?</p> <p>-What do your classes look like?</p> <p>-How do you describe your teaching style/characteristics? (Or, how do you characterize your teaching?)</p> <p>-What are differences between your instructional strategies or activities and the STEM curriculum?</p>
	Knowledge of science/STEM curricula		<p>-What is STEM education?</p> <p>-Are there any changes in science subject matter knowledge that you teach for middle schoolers?</p> <p>-How did you organize the lessons for this semester? (Please tell me about the instructional calendar for the STEM classrooms this semester).</p> <p>-How does student learning/performance differ with the STEM curriculum?</p> <p>-How do you recognize each domain of content within the STEM disciplines?</p>
	Knowledge of students' understanding in science/STEM		<p>-How do you recognize students' understanding of the content?</p> <p>-What kinds of student misconceptions did you recognize in a lesson/topic?</p> <p>-How do you help students correct these misconceptions?</p>

			<ul style="list-style-type: none"> -What do you expect students to learn from your lesson? -Is it more difficult to understand what students know in a STEM class than in a single subject science class?
	Teacher efficacy		<ul style="list-style-type: none"> -What abilities do you want to develop to teach the STEM curriculum successfully? -What challenges do you have in implementing the STEM curriculum? -How comfortable would you feel teaching this lesson?

direct expressions of the research questions, the post-interviews questions were constructed as I observed the classes of the participants. The post-interviews were conducted on the same day as the observation.

Also, I conducted 1-hour individual initial and final interviews. I conducted initial interviews before I observed the participants' teaching to get to know more about their backgrounds, characteristics, teaching philosophy, and orientations to teaching science (see Appendix A). Interview questions included definitions of science, engineering, and STEM education to investigate the participants' perspectives on integrated STEM education based on the first research question. As I had designed semi-structured interviews, the interview questions were changed and added in the context of the participants' answers. I conducted individual final interviews for about 1 hour at the end of the study. Final interview questions were created in the context of the implemented PBL lessons (see Appendix A). The questions included specific learning goals of the PBL lessons, the participants' self-assessment on their teaching, and student assessment of the new curricula. The teachers reflected on their teaching and discussed how to

improve the lessons. In this respect, the final interviews provided specific examples for me to explore the participants' perspectives on integrated STEM curricula and their self-efficacy.

On the other hand, I conducted two individual 1 hour interviews with the assistant principal. Basically, I used the same interview questions as those for the science teachers, but as the assistant principal was the leader of the efforts to reform the curriculum taught by the science department, I focused on investigating the administrator's perspectives on integrated STEM education and school environment by asking additional questions. These included questions about topics such as reasons for pursuing integrated STEM education and challenges from teachers' perspectives.

In order to investigate the influences of STEM curricula on teachers' PCK, I created interview items that were based on the teacher characteristics shown in the six components of the PCK representation adapted from Park and Oliver's (2008b) hexagon model. Therefore, the interview questions covered such topics as the benefits and challenges of STEM curricula and teachers' perspectives on planning and teaching integrated lessons. Interviews were audio-recorded and transcribed for a rigorous analysis of the data to investigate participants' perspectives on STEM curricula.

Observation

I created an observation protocol to guide the systematic observations of the participants' teaching, activities, and discussions with students as shown in Appendix B. This protocol was created to provide focus during the classroom teaching observations, and it included the science and engineering practices in the NGSS as well as examples of teaching activities that would be categorized within the different PCK components. These two aspects of the teachers' teaching were central to understanding the means and extent of teaching integrated lessons.

Moreover, as each school has their own culture, the school environment and support are important for teachers to implement STEM curricula. The category of learning and teaching environment of the observation protocol was included because the school culture and the educational system influence teachers' beliefs and perspectives about teaching (Jimoyiannis, 2010).

Furthermore, collaboration between teachers is helpful for strengthening their understanding of student learning by sharing individual teaching experiences lessons (Furtak & Heredia, 2014). In this respect, the observation protocol included resources, teacher collaboration, and student engagement.

I observed 19 class periods taught by the three participants, four curriculum meetings, and three STEM conferences (see Appendix C). I observed five of Dan's lessons: three PBL lessons and two ordinary lessons. Emily spent three class periods teaching her PBL lessons, so I observed three more ordinary lessons in addition to her PBL classes. Chris was the teacher who spent the most time on PBL lessons, and I observed five of his PBL lessons and three ordinary lessons. Even though the teachers had planned PBL lessons together at a curriculum meeting, they taught the lessons during different time periods.

Also, I observed three STEM student conferences at which students presented their STEM products and research results. At the first conference, students across grades sixth to eighth participated in the conference and presented their STEM products. The second conference was held for presenting the research results of the PBL lessons at the sixth-grade level. Students explained their research goals, processes, and results of the PBL lessons. The assistant principal invited STEM experts from other schools and the Georgia Department of Education, and they



Figure 2. Pictures of the stream activity.

gave students advice after listening to the presentations. The third conference was a science fair to show the results of the science projects that students had done during the semester.

Project-Based Learning (PBL) Lessons

The sixth-grade teachers adopted a project-based learning (PBL) strategy as a long-term project to implement integrated STEM curricula. The curriculum unit was weathering, and erosion was the specific subject of the PBL lessons. The teachers decided to conduct an erosion bottle activity as PBL and created the driving question, “How can we help stop erosion at Norton Middle School?” Although all sixth-grade science teachers used the same driving question for their lessons, each teacher taught with different experiment procedures, materials, assessment methods, and final products of the PBL lessons.

Also, the science teachers planned two activities for the erosion subject to cover the science curriculum: One was an erosion bottle activity for PBL, and the other was a stream activity. The stream activity was not for PBL but for teaching how to form a river system by the



Figure 3. Pictures of the erosion bottle activity.

processes of erosion and deposition. As shown in Figure 2, the stream activity was for learning about how a stream forms by pouring water on sand. The teachers scheduled a stream activity together because they had to share one stream table for the activity. The stream activity was conducted at the same time as the erosion bottle activity for the first class of the PBL lessons. The teachers conducted only the erosion bottle activity in the second class of the PBL lessons.

Erosion bottle activity. The sixth-grade teachers conducted an erosion bottle activity through PBL as a way of implementing the integrated STEM curriculum. The teachers thought that PBL is an appropriate instructional approach that includes some characteristics of STEM lessons such as integration of science and mathematics. Students conducted the erosion bottle activity to find solutions to stop erosion at the middle school.

The erosion bottle activity allowed students to design and build a water bottle that would provide clean water by putting three materials into the bottle (see Figure 3). The students brought their water bottles for the activity and filled half of the bottle with soil and put three kinds of materials to cover the soil. Students had to decide what materials they would use and how to put

the materials in their water bottles. The materials the students were allowed to use were different according to the teacher. One teacher prepared all the needed materials, and the others made students bring their own materials from home. After preparing the water bottle, the students placed collection cups under the nozzle to collect filtered water. Then, the students poured water into the bottle over the top of the soil in the bottle and then into the collection cups. The students evaluated the clearness of the water. If they got clearer water, it meant that little erosion occurred. If the students were not satisfied with their results, they repeated the experiment after making modifications such as changing materials or the order of the materials. The purpose of this activity was helping students to gain ideas to stop erosion at their school environment.

All three participating teachers gave their students the worksheets describing the procedures of the activity, but procedures and assessment of the activity were different depending on teachers. Detailed differences are described below.

Teachers' Classes

Dan's lessons. Dan taught earth science for two gifted classes and two general classes at the time of the research. I observed one of the general classes that consisted of 25 students during this study. He assigned three class periods for the PBL lessons and conducted a stream activity on the first day of the PBL lessons. There were six groups of four to five students in the classroom, and one group experimented with a stream activity while other groups conducted an erosion bottle activity. When the group finished the stream activity, they turned to the erosion bottle activity and the other group joined the stream activity in turn. Dan led the stream activity. He explained all the processes of stream formation and instructed the detailed activity processes.

The students conducted the erosion bottle activity independently based on the worksheets. Although Dan handed out the worksheets which described the activity procedures,

he did not explain the content. Thus, his students had to read instructions and conduct the activity by themselves.

Dan's PBL lessons consisted of three sections of the three class periods. For the first class, students conducted an experiment as a group with a small water bottle (8oz.) and the stream activity. Dan allowed students to use any three materials from the classroom such as paper, paper towel, pebbles, or pine tree straws for the erosion bottle activity. The students designed and built a water bottle in a group. After building an erosion bottle, they poured water into the bottle and collected the water and checked its clarity. They repeated the experiment to gain clearer water and compared it with the other groups' results. Dan conducted a demonstration and explained how a stream is constructed through the stream activity.

In the second class of the PBL lessons, the students continued and finished their previous experiment and had the class discussion about the results. Dan reviewed the vocabulary relating to weathering and erosion and gave students a quiz about the two activities.

In the last class of the PBL lessons, the students went outside and designed an erosion bottle using a big water bottle (16.9 oz.) for each group. Although Dan prepared some natural materials such as mulch and pebbles, the students freely chose three materials in the area assigned by the teacher. Dan did not give his students specific rules for selecting materials. Thus, some students used their notebook paper and others collected and used leaves or pine tree straws. After coming back to the class, Dan collected each group's erosion bottle and examined the results by pouring water into the students' bottles. The teacher and the students evaluated the results of their products together as in a competition by comparing the clearness of filtered water (see Figure 4). Students wrote down their scores based on their ranking of the clearness of water. Dan provided the criteria for obtaining the points. There was no time to discuss the reasons of the results or solutions to the driving question. Dan and his students focused on getting clear water and did not discuss how this activity related to the driving question.

Emily's lessons. Emily taught two science classes and two mathematics classes. I observed one of the general science classes in which there were 23 students. She assigned three



Figure 4. Pictures of the erosion bottle activity at Dan's class.

class periods for the PBL lessons. She rearranged the schedule so that students were in her classroom for two consecutive class periods when conducting the erosion bottle activity. To this end, she switched classes with another teacher in order to implement the erosion bottle activity without interruption due to the class time limitation. Thus, her students were able to perform the activity during two continuous class periods. Emily's students also conducted the stream activity with the erosion bottle activity in the first class of PBL lessons.

However, her class was different from Dan's class in that she had her students conduct all procedures by themselves. She gave the students detailed procedures for the activity through worksheets and answered the students' questions related to the activities. Emily prepared three materials that her students used for the erosion bottle activity. So, her students used the same kinds of materials but different amounts of the materials. Also, the students used only one water bottle as a group over the entire process of the activity, so they washed the bottle if they wanted to construct the erosion bottle again. Only group work was involved, and there was no individual activity (see Figure 5).

She had her students try to solve problems before asking her questions. She focused on teaching science vocabulary regarding the content, so she gave a vocabulary quiz and reviewed it for each class. Her PBL lessons were taught based on the worksheets on which students had to answer the simple questions or write experiment procedures and their comments. Emily had



Figure 5. Some pictures of Emily's class.

students upload the pictures of their results, purified water, on the class website using a cell phone. In the third class of PBL lessons, Emily and her students discussed their results and compared the clearness of water through pictures. The students reflected on their procedures and results of the activity.

Chris' lessons. Chris taught three science classes, and I observed one of them with an enrollment of 25 students. Among the three participating teachers, he devoted the most class time to the PBL lessons, five class periods. He taught PBL lessons throughout four class periods and held a conference during the fifth class for his students to present their project results. Chris had each student take a specific role for the activities in their group, such as leader, reporter, or organizer.

For the first class, his students studied the environment of the school and planned their projects; this involved deciding on their target place for the activity by examining the pictures of the school environment, identifying the problems, and finding solutions. In the second class, the

students conducted the erosion bottle activity and the stream activity. The students shared the materials they brought from home and built an individual erosion bottle for the activity.

One thing that was different from the other teachers' lessons is that Chris' students designed individual bottles and conducted their own experiments. Then, they formed groups and repeated the activity to build their group's erosion bottle. Two groups of the students conducted the stream activity and took turns. The students watched a video that showed how to conduct a stream experiment. Chris handed out the worksheets describing all instructions and did not give answers when his students asked questions related to the activity. He organized and facilitated the class but did not become involved in his students' activities.

In the third class, the students built the group's erosion bottle based on the results of the individual bottles built during the previous lesson. Chris provided a criterion sheet showing turbidity pictures for assessing the experiment results. At the end of the third class, the students discussed each group's turbidity based on self-evaluation and wrote down answers to the questions on the worksheets.

In the fourth PBL class, the students created a proposal based on their experiments using Google Slides and Dropbox. Chris had difficulty instructing students on the use of Google Slides because most of his students did not have experience with it. Chris integrated technology with his PBL lessons to help students to learn how to organize and present their ideas effectively using technology. For the proposal, the students went out to see the surrounding environment of the school to decide on the target place of their proposals. Chris provided several pictures of the school environment to help students choose the target location. After coming back to the classroom, the students created a Google Slides presentation.

In the fifth and final PBL class, Chris held a student conference and invited an audience. His students presented their proposals including procedures, results of the activity, and suggestions for their school environment using Google Slides.

Curriculum Meetings

I observed four curriculum meetings that the teachers used as collaborative times for creating integrated STEM lessons. At the first meeting, sixth grade science teachers, James the assistant principal, and a STEM coordinator participated in the meeting. They discussed the timeline to teach PBL lessons and the order in which they would use the stream activity equipment. The teachers initially planned repeated experiments for the students to build their individual bottles and modify them to design a group bottle. However, Chris was the only teacher who followed this plan among the three participating teachers. Other participating teachers only had their students create a group bottle for the activity.

The science teachers also discussed how to assess student achievement in PBL lessons and examined the state's standards for the weathering and erosion topic. The teachers thought that they had to conduct a formative assessment, and Chris shared examples of assessment questions to discuss with the teachers. However, they did not reach a consensus on the assessment methods. Even though the STEM coordinator participated in the curriculum meeting, she did not give comments on the assessment issues.

During the second meeting, the teachers shared difficulties such as time management or classroom organization when teaching the PBL lessons. They also discussed increasing student engagement through conducting the PBL lessons. In addition, the teachers talked about how to involve language arts teachers in teaching students argumentative writing and designing future plans for the extension of PBL lessons.

Data Analysis

The thematic analysis method was used for analysis of data generated in this study. In the process of thematic analysis, open coding and constant comparative analysis methods (Glaser & Strauss, 1967) were used. Thematic analysis is applicable for social and psychological interpretations of data and allows the discovery of unanticipated insights (Braun & Clarke, 2006). Furthermore, thematic analysis is useful for identifying the key features of the data. In this respect, the thematic analysis method was suitable for this study because this study identified teachers' obstacles to implementing integrated STEM lessons and their perspectives on STEM curricula. Thematic and inductive analyses were performed to identify patterns and themes in the data after open coding and line-by-line coding. Charmaz (2011) argued that line-by-line coding is helpful for researchers to be involved in the analysis and to describe their preconceptions as well as incidents that happen in the data. I coded interview transcripts, field notes, and observation sheets through open coding and line-by-line coding.

Constant comparative analysis is an inductive way of conducting thematic analysis, and an inductive approach allows themes to be identified by linking them to the data (Patton, 2015). In the process of data analysis, I constantly compared transcripts, codes, categories, and themes to identify meaningful findings. Also, I did not use an existing coding frame but inductively emerged codes by adapting the constant comparative analysis method.

During the initial open coding, I wrote memos when conflicts were found or when I found different perspectives between the participants on the same issue. After finishing the initial open coding, I also wrote memos to analyze the initial coding and examine the categories. As Charmaz (2011) asserted, "Memo writing is a pivotal strategy that prompts the researchers to engage in early data analysis and writing about their emerging categories" (p. 172).

For the second round of coding, I examined the transcripts, field notes, observation sheets, teachers' worksheets, and students' work samples again. I merged similar codes and reduced overlapped codes. I also reexamined initial categories to clarify meanings from the emergent codes.

Themes are not driven by an existing coding frame or my theoretical interest, but by data. For triangulation of the data sources, I collected data from different sources, such as interviews, observations, and student work samples, and interpreted these data to investigate teachers' beliefs and perspectives on STEM curricula.

When I analyzed data in terms of the development of the teachers' PCK, I adapted the "PCK evidence reporting table" (Park & Oliver, 2008b) and modified it based on the hexagon model of PCK (Park & Oliver, 2008b). In order to classify teachers' orientations to teaching science, I employed characteristics of instruction with different orientations to teaching science (Magnusson et al., 1999, p. 101): process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry.

I used qualitative data analysis computer software, NVivo 12, for finding themes effectively. This software helps researchers to analyze qualitative data by storing, indexing, sorting, and coding data that are essential elements for constant comparative analysis (Leech & Onwuegbuzie, 2011). Using NVivo 12, four categories were created based on the research questions: benefits of integrated STEM education, challenges to implementing integrated STEM lessons, the administrator's perspectives, and the erosion bottle activity. Under the categories of the administrator's perspectives and the erosion bottle activity, there were subcategories such as benefits, challenges or definition of STEM education. By employing NVivo 12, I systemically

categorized the codes and repeated data analysis effectively. This resulted in finding meaningful themes for this study.

Summary

In this chapter, I described the qualitative research methodology, specifically a multiple case study, which was used for this research. The participants were three sixth grade earth science teachers in a public middle school (this study's research site) which was preparing to teach integrated STEM curricula. I collected data from different sources including semi-structured interviews, observations, teachers' instructional materials, field notes, and student work samples. I presented detailed descriptions of the participants, the research site, and the lessons. Thematic analysis method was used for data analysis in this study. I conducted open coding and constant comparative analysis with qualitative data analysis computer software, NVivo 12. In the next chapter, I present the findings of the study.

CHAPTER 4

FINDINGS

In this chapter, I present the findings of this study organized under four sections. First, I discuss three middle school science teachers' perspectives on integrated STEM education focusing on benefits and challenges of implementation of the project-based learning (PBL) lessons. Second, I present the results of an investigation into the science teachers' teaching of the PBL lessons in terms of the engineering design process. Third, I explore the development of the participating experienced teachers' pedagogical content knowledge (PCK) in the context of the participants' teaching of the PBL lessons. Fourth, I share my analysis of an administrator's perspectives on implementing integrated STEM lessons. In particular, I examine what differences and similarities exist between the administrator's and the science teachers' perspectives on the integrated lessons.

In this study, the participating middle school adopted PBL as an initial step toward implementing a science curriculum based on integrated STEM education. The assistant principal, the administrator participating in this study, who was providing leadership for implementation of the PBL lessons explained that PBL is appropriate for their school as an introductory step used to gain insights into integrated STEM lessons and would be a way to more easily transition to teaching integrated STEM lessons. The participating science teachers were aware that their PBL lessons were the preliminary stage of teaching integrated STEM lessons. Therefore, I

investigated implementing the PBL lessons to explore teachers' practical difficulties and their perspectives on teaching integrated STEM lessons.

Experienced Science Teachers' Perspectives on Integrated STEM Education

In this section, I discuss experienced science teachers' perspectives on implementing integrated STEM lessons. The analysis of data has resulted in a structure to these findings that will be presented in three parts. First, I explore the participating teachers' perception of the meaning of integrated STEM education. Second, I examine what the teachers consider to be the benefits of teaching integrated lessons for student learning. Third, I investigate practical challenges that the teachers confronted when they implemented the integrated lessons.

In the literature review, I introduced four approaches to teaching integrated STEM education that had been synthesized from the literature. As a review for the reader, these will be re-introduced here. There are four approaches to teaching integrated STEM that has been labeled as: the illusion approach, the enhanced approach, the generalized approach, and the specialized approach. As described in more detail in the literature review, the illusion approach happens when the teacher perceives that there is no STEM education representing a unique approach and that the term STEM, which already existed as an instructional method, is a response to the social needs based on economic or global pressure. The illusion perspective usually appears when new teaching and learning approaches are presented. The enhanced approach is in evidence when stakeholders perceive that STEM education has been implemented to support science or mathematics education by the integration of other disciplines, particularly technology and engineering (Lederman & Lederman, 2013; Roehrig, Moore, Wang, & Park, 2012). This approach focuses on science or mathematics education and considers technology and engineering as supportive disciplines. The generalized approach occurs when stakeholders perceive that the

term STEM education refers to education in each of the STEM disciplines. The generalized approach does not assert a goal of integration of all four disciplines, but rather focuses on the outcomes that arise from integrated STEM education such as improvement of student achievement or interests of careers in STEM fields. The specialized approach perceives that STEM education refers to integrated instruction in STEM disciplines.

The Meaning of Integrated STEM Education for In-service Science Teachers

The participating teachers understood the term of *integrated STEM education* to have two meanings which shaped their classroom teaching goals: First, integrated STEM education was an approach to teaching that combined domains (i.e., science, technology, engineering, and mathematics) of STEM fields; and second, they viewed it as an introduction to future careers in the STEM area for their students.

Dan and Emily perceived integrated STEM education as an instructional approach which had a primary purpose to teach the STEM subjects in an integrated fashion. More specifically, based on the categorization as presented in Table 2 (see p. 14 in Chapter 2), Dan demonstrated both the specialized approach and the illusion approach. Within the specialized approach, there were variations in how teachers implemented the teaching of integrated STEM across the four domains. Dan, for instance, perceived that integrated STEM education means connecting two or more of the STEM disciplines within the context of classroom curriculum and instruction. Dan explained that STEM is “combining science with technology and a lot of different things and putting them together.” However, Dan also exhibited the illusion approach that STEM education is not a new instructional strategy but has existed within traditional science education as he had implemented it in his classroom. This lack of difference between his original science classes and the integrated STEM lessons occurred because he had been teaching innovative things in STEM

fields including hands-on activities throughout recent years. In his case, Dan's traditional teaching can be considered to contain integrated STEM lessons. For instance, when he taught rock composition, he had his students create song lyrics which used rhymes based on the names for the mineral ingredients of rocks. Further, his students made their music books using computers and related technology. Thus, his traditional teaching had included music and technology in his science classrooms.

Emily used a more restrictive operational definition of teaching integrated STEM curricula. She expressed the specialized approach, but in contrast to Dan, she understood that STEM education connects together the domains of science, technology, engineering, and mathematics. She said that "STEM is just making connections, making sure that all four academics [the four STEM domains] and everything that they do all connect together." Even though Emily often connected mathematics and social science with her science teaching, she thought STEM education should include all four domains, so she did not consider her lessons as integrated STEM lessons.

Chris, on the other hand, applied the general approach that focused on the practical function of STEM education. He described STEM education as meaningful in that it provides opportunities for students to learn about various jobs in STEM fields and to acquire hands-on experience with processes employed by professionals in those fields. He explained that STEM education in middle school can encourage students to study STEM subjects in high school and to think about STEM careers as their future jobs. Through this part of the analysis, it can be seen that while Chris focused on practical career-related outcomes as a primary goal for his implementation of integrated STEM education, Dan and Emily placed greater emphasis on an instructional teaching approach which integrated the domains of science, technology,

engineering, and mathematics as a way to expose the students to more contemporary problems of our society.

Benefits of Integrated STEM Education for Student Learning

Real-life problem-solving and real-world applications. In general, integrated STEM education provides opportunities for students to apply academic knowledge to real-world problems (Brophy et al., 2008; Sadler et al., 2000). The research literature suggested that students easily apply their knowledge to real-world problems because most integrated STEM lessons include real-life topics to engage students in their lessons by connecting their lives with learning.

All three participating teachers perceived the application to real-world problems as a benefit of integrated STEM lessons. Emily said that “They see the purpose and application to realize what they've learned from a bottle [the erosion bottle of the PBL activity] then applying it to going outside and doing the same thing.” In particular, Dan described that students easily forgot what they learned in the traditional science classes even if they conducted the same activity with the STEM lessons. Dan said:

This is something I learned in a fast run, but now, you know, this is the positive side of the real world. And kids sometimes don't get that. They think I learned something in class, and I forget about it. Well, that's not the way the world we live in is. You take it and you apply to something else. (Dan, Interview #2)

This perception is consistent with the finding of argumentation by Jonassen et al. (2006) that states that students have difficulty solving real-life problems because those problems are ill-structured, but students learn well-structured problems in classrooms. Real-world problems occur in diverse situations, not in fixed conditions. Most everyday issues are ill-structured that have

multiple solutions, and students should consider multiple criteria to solve the problems (Jonassen, 2000; Jonassen et al., 2006). For example, engineers have conflicting goals such as the best function of the product and cost to meet the client's needs. In this study, the students kept thinking about their lessons through designing how to apply the results of the erosion bottle activity to their school environment. In other words, students brought their learning in classrooms into the real-world situation as Chris said below:

I think that the only difference [from the traditional science classes] that I can see is that they [students] would be doing the same activity, but we try to bring it to a real-world application. We walked outside of the classroom. We did the lab and then we tried to make an application of that towards our own environment or their own world... I think that we try to do more projects so [students learn] how it impacts the real world around you. (Chris, Interview #2)

These statements indicate that the PBL lessons included ill-structured real-world problems connecting with students' real lives that stimulated the development of real-life problem-solving and application abilities.

In addition, Chris described that integrated STEM education makes science knowledge real for students. This learning is not literal knowledge in a book but rather real and live knowledge in students' lives. Chris said that integrated STEM lessons lead students to expand their learning outside the classroom by adapting their science to the larger community, such as the regional or global community. Chris explained,

It's more of an extension. It's not only an extension and it's a real-world application. I feel like the PBL forces me to think beyond, okay we did this experiment in class and this is what you found out and leave it at that. I think

we're trying to stretch it to “what and how can you use this?” How it’s used in the real world. So, the more we can add and make that a reality for all these kids, I think the better it will be. The kids enjoy it. They have enjoyed doing it. (Chris, Interview #2)

The participating teachers described that the PBL lessons helped students to develop problem-solving abilities, especially real-world problem-solving. The students were used to studying content in the textbook and solving problems in a given condition presented in the book, but they met unexpected situations like a pop quiz when they conducted the erosion bottle activity. For example, a group of students obtained different clarities even though they used the same cover materials in the erosion bottle. They were taken aback at first, but then discussed each other and repeated the experiment to find reasons for that. As a result, the lessons helped students to engage in their classes by enjoying the application process.

Out-of-the-box thinking/Unconventional thinking ability. In addition to the real-world application, Dan perceived developing unconventional thinking abilities as a benefit of integrated STEM education. He said that most of the classroom instruction in his ordinary classes included hands-on activities, but the PBL lessons he implemented were different in that the students could apply their knowledge to the new situation and consider unexpected elements when they solve real-life problems. Dan labeled this ability as thinking “outside the box.” He stated,

It's more of an application, you're taking some of your learning, now you're finding something in a new situation... You might be able to see the relationship between this and this, but you see the relationship between this and something over here. And that's real problem solving, that's thinking outside the box, and that's when you got to think at the hard level.” (Dan, Interview #2)

Through dealing with these unconventional situations, students develop the ability to cope with real-world problems (Jonassen, 2000). The PBL lessons in this study were different from the traditional science lessons in that students met unexpected cases which are not in the textbook.

High-Order Thinking Ability. Unconventional learning outcomes discussed above can be categorized into one of the high-order thinking abilities based on the Structure of the Observed Learning Outcome (SOLO) Taxonomy (Biggs & Collins, 1982). Biggs and Collins (1982) categorized learning outcomes into five levels – pre-structural, uni-structural, multi-structural, relational, and extended abstract – based on complexity and quality of student outcomes (see Table 5 p. 37 – Chapter 2). In describing the student actions that are required to complete tasks at the higher levels (i.e. relational and extended abstract), objectives are phrased with verbs such as *analyze, apply, argue, compare/contrast, criticize, explain causes, relate, justify, create, formulate, generate, hypothesize, reflect, and theorize* (Biggs & Collins, 1982). These verbs are also used in the analysis to examine the teachers' goals for setting the level of cognitive accomplishment expected from the students.

This analysis showed that the participating teachers set learning goals for students to develop high-order thinking abilities through teaching the PBL lessons. More specifically, the teachers planned the procedures of the lessons for students to *create* students' own erosion bottle models, *analyze* their experiment results, *applied* what they learned through the activity to their school environment problem, *argue* their designs' effectiveness, *explain* why they selected the particular materials and *reflect* on their work. The teachers also prepared worksheets to fill out while conducting the erosion bottle activities. The questions on worksheets also included questions to have students reflect on the processes and results of the project.

In particular, Dan mentioned the development of metacognition thinking ability. He thought that his students evaluated their own products while assessing others' products. Through this evaluation process, the students reflected on their work and themselves. Dan explained:

I think STEM offers them the ability to problem solve, to evaluate each other and themselves. You know that metacognition thinking about thinking is one of the hardest things to do. (Dan, Interview #1)

Dan's description shows that the development of high-order thinking abilities is a benefit of integrated STEM lessons. The teachers planned and implemented the PBL lessons to help students naturally develop high-order thinking abilities such as problem-solving abilities, creativity, evaluation ability while they conducted the erosion bottle activity through PBL.

Engagement and Motivation

All three participating teachers perceived that their students enjoyed the activities and projects. The teachers described that students liked doing science activities such as labs, but many lab activities focus on demonstration of science knowledge, and students are not interested in the simple work of confirming existed theories. The students were motivated to participate in the activities because the PBL lessons included challenges that the students were engaged in their lessons to resolve those challenges. Emily explained as follows:

When you have the usual silliness in all of that, but they were really focused.

Usually, when they are presented with a challenge, these kids get very focused. If it's just doing the traditional thing then you have the usual, "I don't want to do it." and they just sit there. But they were excited about it. Plus pumping it up [competition announcement of the erosion bottle activity] ahead of time is a motivational factor too. (Emily, Interview #2)

This statement implies that providing students with a challenge helps to supply the necessary motivation to pursue the desired learning. In contrast, lessons that follow traditional formats tend not to capture students' interests. The PBL lessons in this study showed much potential for providing the students a means to trace their own academic track while conducting the activity. The students designed their own models of the erosion bottle, so they were able to embody their idea freely based on their interests. For example, some students placed only natural materials such as mulch or leaves on soil and others used artificial materials such as paper or paper towel. The students built their erosion bottles with cover materials that they want to put on the soil.

Furthermore, as each of the students in Chris' class was supposed to create an individual erosion bottle prior to building their group's bottle, the students were initially in charge of the design of efforts to build their own bottles. Chris asserted:

I think they're more engaged and they have more ownership in what they're doing, and they really do to make it their own. So, I think it gives them a sense of accomplishment for themselves and I think that's probably where I see PBL or STEM (Chris, Interview #2)

Chris pointed out his students were more engaged in their lessons because they had ownership in their products, and they had a greater sense of achievement through their actions. Chris' lessons were different in that he gave his students an opportunity to make individual bottles before joining the group work. This individual work complemented the potential problems of the group "bottle construction" activity which is often documented to be dominated by a few students while others just look on without participating in it.

Some of the teachers noted significant benefits that arose from the group work. For instance, Dan mentioned the role of peer pressure as a motivator. As each of his PBL lessons

included group work, he thought that peer pressure functioned as an accelerant for students to participate in their lessons. The PBL lessons required students' active participation that ranged from the preparation of the materials for the projects to the creation of the final products. Dan elaborated this point as follows:

Somebody in your group showed up and they didn't bring anything with them, well, that's the problem for the whole group. And I love that because the other group members will start holding people accountable. Because if I brought my stuff in, and the other person brought their stuff in, you didn't bring your stuff in, "Hey, what's up?" Peer pressure sometimes can be a great motivator, more than me saying, "Where's your stuff?" So, a lot of times when I walk around and I see that happening like somebody walked in without it, I just don't say a word, I just give them a look and they'll start talking before I say one word. They'll start talking, "I left it at home." So, what are you going to do then? You know what's going to be done. (Dan, Interview #2)

The PBL lessons were a long-term group project that was largely influenced by each group member's participation, and peer pressure produced a positive effect on students' engagement.

Moreover, the three participating teachers perceived that integrated STEM lessons consist of hands-on activities that encourage students to engage in their classes. For example, Dan mentioned that while students hardly have opportunities to talk and collaborate with each other in lecture-based lessons, integrated STEM lessons provided a place and time to discuss. The students learned to really love to "do" science. He said:

It's very hands-on, it's very active. Kids like to talk. They like to collaborate with each other and [they learn that] there's a time and a place. There's a time when I

want you to talk and expect you to talk and there are times when you need to listen... Another interesting part of STEM I think, and PBL is doing all these kinds of stuff hands on. And seeing the process, to me, that's the interesting thing, it's the process. I love that, but I love seeing how they get there. And that's the fun part. (Dan, Interview #2)

This statement supports that hands-on activities in STEM lessons are significant in that they provide a student-centered learning environment. The students actively participated in the erosion bottle activity and freely discussed with their classmates under the student-centered learning environment.

Teamwork Skills and Communication Ability

Team members' active participation and communication abilities influence group work's success. All three participating teachers organized their students into groups when conducting the PBL lessons in a group, so the teachers expected their students to develop teamwork skills and communication abilities by listening to peers' opinions and feedback. In doing contemporary science and engineering, it is reported that most work of scientists and engineers is conducted within a group work structure, and students who are working in groups can also learn to develop teamwork abilities for the twenty-first century (ABET, 2014).

Collaboration with others and work experience as team members are beneficial for students to obtain through integrated STEM lessons. The students discussed their ideas in a group for selecting the group's erosion bottle model and collaborated each other to find the best solution. Communication skills are also essential for presenting outcomes to an audience. Students can learn how to effectively express their achievement by presenting their ideas. For

instance, Chris expected that students learn teamwork skills and communication skills through practicing verbal and written expression as well as problem-solving:

They [students] have to say what their outcome was, and each table group has to have someone speak. So, I think it builds students' skills in speaking and communication more than just in science. It teaches them a sense of teamwork as I've said and expression, verbal expression, written expression, problem-solving. They have to work together to come up with solutions in time or see what the outcome really means. They like it. They like coming here. (Chris, Interview #1)

Furthermore, the students created the learning community in all three participating teachers' classes. When a group of the students struggled with their experiment, they often asked other groups rather than teachers and helped each other. They referred to other groups' work and communicated between groups to find the more effective models of the erosion bottle. Dan explained how the students constructed the learning community and emphasized the importance of feedback from classmates as follows:

They see other groups demonstrating what they did, and they see how the other groups work together to get it done, then they understand. And that's when they say, 'that's where we messed up'. But that goes back to feedback too. I think feedback is so important, not just for me, but for other people. Because sometimes they would listen to other students better than they listen to me. And if they see another student having a problem, and they're having the same problem, they can relate to each other. But they may not hear it from me. Or they might be afraid to come to ask me because they don't want me to know that they don't know, so

they'll try to hide. But that's another interesting part of STEM I think, and PBL is doing. (Dan, Interview #2)

Dan's account can be understood by considering the teenagers' characteristics. Especially, for teenagers, relationships with friends are important, and they want to be recognized as a good team member (Erickson, 2007). Therefore, the students take into account classmates' feedback when they conduct group work. This is also helpful for understanding Dan's perception of students' self-esteem. He described that students love to share their knowledge with peers, and it helps to strengthen students' self-esteem as well as motivation to learn. He stated:

It's going to show up and the fact that they know from the very beginning, you're going to have to present what you did to the class. There's an added pressure there. And it's the time to shine because I get to stand up in front of the whole class and show how smart I am in front of the whole class. Some kids thrive on that, and they should. (Dan, Post-interview #3)

The presentation can be a valuable experience for students in that it gives a success experience to the students. This small success experience often stimulates students to move forward and motivates them to learn.

Challenges to Implementing Integrated STEM Lessons

Assessment of Student Achievement

Assessment was the most difficult obstacle that the three participating teachers faced when they implemented integrated STEM lessons. As the middle school did not have formal rubrics or references for assessing student outcomes through teaching integrated STEM lessons, the teachers had to create or collectively decide the assessment methods. However, at a curriculum meeting for the PBL lessons, as the sixth-grade science teachers did not reach a

consensus regarding how to assess student achievement of integrated STEM lessons, the teachers began to teach the PBL lessons without detailed criteria or materials for assessment as shown in Emily's statement below:

That's what we're still in the works. So, we need to, Monday, we should be planning to figure out what assessments we're going to do along the way. (Emily, Interview #1)

The participating teachers said that they had no standardized methods for assessing student outcomes except the standardized test such as the Gwinnett Academic Knowledge and Skills at the end of the semester and had difficulty assessing student achievement that resulted from teaching integrated STEM lessons. Chris reported:

I can't quantify that and say that this particular group did this better and so much better than this group that didn't have that. That's something that you can look at later maybe with the district assessments. (Chris, Interview #1)

Chris depended on the standardized test to evaluate student achievement. However, student outcomes that might result from implementing the new curricula are difficult to assess using the traditional standardized assessment methods (Yager & Tamir, 1993).

During the PBL lessons, formative assessment was conducted to evaluate student understanding about the lessons by asking simple questions about science concepts. All three teachers kept checking student progress on learning the vocabulary about weathering and erosion and observed students' activities. The teachers believed that their students achieved academic knowledge of the erosion through the PBL lessons. Chris explained:

I think that they understand that you have to have certain controls...to stop soil erosion. So, I think that was successful, that's part of it. I think they all

understood what we were doing. I do think that they understood the fact that if you don't have ground cover then you're going to have erosion. If you have something to stop that. I knew that maybe some of them even knew that if you have leaves and pine straw and sticks down, you're going to have less erosion than having nothing [in place over the bare soil]. But it was just really the fun of the aspect of learning. (Chris, Interview #2)

Chris observed students' work and gave oral comments on it over the time allocated for the project. He conducted the formative assessment by observation and questioning to probe students' understanding of the erosion bottle activity. He thought his students achieved the learning objectives that understand roles of ground cover materials to stop erosion. However, when it comes to limited assessment methods, more systematic assessment strategies are necessary for learning about student outcomes through integrated STEM lessons.

As shown in the conversation with Emily below, as has been discussed regarding other teachers, she did not have exact criteria for evaluating student outcomes of the PBL lessons. Moreover, Emily expressed concerns about her teaching because she was not sure if she taught everything that her students were supposed to learn through the PBL lessons. When she was asked a question about how to assess student achievement, she answered as follows:

Well with that, it was mostly just observation because since this is my first time and their first time, I did not know what to expect. So as long as they came up with the idea and I assisted through them posting their pictures [pictures of filtered water of the erosion bottle] and then had the kids compare with each other. But I mean I didn't do a formal assessment with anyone...I feel like I'm going to miss something, or I won't have time for that. It could go on forever. Or

am I really teaching them exactly what they need to know by doing this one activity? So, it's a little stressful and I'm a little hesitant as we go further into it.

(Emily, Interview #2)

This statement indicates that the lack of appropriate assessment methods and the teacher's limited knowledge of assessment of student learning influenced the teacher's instruction. Emily did not conduct a formal assessment because she did not know how to create the assessment, so she did not know exactly what students accomplished. Because every group of students had the potential to create different products and there were no formal criteria, the task of assessing the students was stressful to her. This result is consistent with the research by Stohlmann et al. (2012). In the research, the teachers had little confidence in instructing the students' creation of Rube Goldberg machines because the students designed their own machines so that the teachers did not know what direction students would go in the lessons. Consequently, she was not sure to what extent she had to teach the erosion bottle activity. On her worksheet, Emily asked vocabulary questions and about students' conclusions of the activity, but formative assessment methods are also needed to support teachers to prove that student learning took place during the activities.

Dan assessed student achievement based on the experimental results of the final product. It was a simple scoring according to the clarity of the filtered water even though the questions included the preparation and procedures of the erosion bottle activity. Dan wanted to improve his assessment methods by including written assessment and self-assessment in his future lessons. Dan emphasized his perception of the importance of self-assessment where the students evaluate themselves. He wanted students to think seriously about their own accomplishments by reflecting their work, stating:

If I do that again, I will have some written assessments along the way. And I think the written assessments are not necessarily going to be from me. I think they're going to be self-assessments and I want them to, I want them not only to assess their little group that they might be in, but the kids would also be really honest especially when they're talking about themselves, you wouldn't think they would be. But a lot of times, they are more a lot critical of themselves than I ever would be. (Dan, Interview #2)

Discussing their own accomplishments, reflecting on their activities during this PBL lesson, and being critical of their work are all means of developing metacognitive thinking abilities. Also, self-evaluation, reflection, and feedback from peers contribute to learning about their processes and social interactions (Bell, 2010). Dan acknowledged what he has to strengthen in terms of assessment methods for his future lessons.

Elementary Curriculum

One interesting finding of this study is that the participating middle school in-service teachers thought that the curriculum used for teaching science in elementary school is an obstacle for teaching science as well as integrated lessons. Dan and Emily asserted that middle school students have little experience with science in elementary school, so students are not familiar with scientific vocabulary and content. They thought this lack of experience with science make students have difficulties learning science and little confidence in their ability to do so. This results in decreasing interests and engagement by the students in science classes. Dan asserted this as follows:

They[students] are coming into me, from elementary school would be very limited science. Science is kind of put on the back in elementary school because

they had a purpose on Math and Language, Arts, Reading and I understand that. But they're kind of expected to know some things that maybe they're not ready for. Some science terminology is sometimes difficult for them because they're not used to the scientific way of hearing something phrased. And even on a test, one word could throw them off on the test question because they're not used to the way that's being said. And I think it's just the different way of reading information, understanding information, discovering information, taking it apart and putting it back together. They've never really had a science class before and now they're thrown into a real science class where they're being held accountable and, you know, that can be tough for some kids. (Dan, Interview #1)

Emily supported Dan's argumentation, stating:

There are a lot of students have difficulty learning science [in middle school] because the elementary curriculum, it's so choppy. They learn this, this and this from all over the different sciences that somehow would strengthen one area, where others, they may spend a week on it, and they don't have that strength. And some, they've never even heard of these things. They don't have experiences of volcanoes erupting, they've never seen footages of these coming in, they've just had never heard or seen of these things. So, just their life experience could be limited too. (Emily, Interview #1)

Each of the three participating teachers focused on teaching science vocabulary to overcome an important part of the obstacles described in the quotes above. The obstacle associated with vocabulary is not limited to teaching integrated lessons, but rather science broadly. However, for science teachers, obstacles for teaching science definitely affect teaching

integrated STEM lessons. In summary, the teachers' perception of the absence of science teaching in the elementary school classrooms presents challenges for their teaching of integrated STEM lessons in the middle school and more generally for the middle school curriculum.

Limited Resources

One of the difficult challenges in terms of resources for implementing integrated lessons was limited space for conducting activities in this study. All three participating science teachers mentioned the absence of space as an obstacle for teaching the PBL lessons. Dan's statement below gives a representative example of this obstacle:

Look at my room. There's no way to put anything and there's no storage area. So, if you're having somebody work on a project, and it's a long-term project, where do you put it? You know, it's always somewhere, someplace where you can have it. Space is always a premium. (Dan, Post-interview #3)

The first issue was the time required for the new form of lessons. In particular, the PBL lessons in this study lasted from three days to three weeks according to each teacher's plan. Therefore, the science teachers had to store their students' ongoing products in their science classrooms for multiple days. The teachers each taught four or five classes per day with 23-26 students per class, so keeping all products were not easy without additional space for storage at the school. Adequate space for activities is the minimum requirement for a long-term project.

Human resources were another challenge. Even though the middle school had a STEM specialist who participated in the curriculum meeting for designing integrated STEM lessons, she did not suggest any directives during these meetings. Even when the science teachers struggled with planning and organizing the PBL lessons, the teachers did not ask for help from the STEM specialist. Rather, the teachers asked each other and referred to other science teachers' lessons.

For example, the science teachers decided to implement the erosion bottle activity as a project for the PBL lessons because Dan, who was a very experienced teacher, had been conducting the activity for a few years. However, Dan also struggled with the PBL lessons because in the past he had just demonstrated the use of the erosion bottle as a classroom activity and had no experience with this activity as a student project. He described this contrast as:

I've done this [erosion bottle activity] demonstration before but never done it with the kids before, so I was kind of in the dark of how long it will take, those kinds of things. (Dan, Post-interview #4)

As there was no expert with the erosion bottle projects, the participating teachers had difficulties when they confronted unexpected problems such as including technology, time management or assessment methods.

Chris also mentioned the needs of specialists outside the school related to the content and assessment. He said,

I think that we had talked about bringing in an outside source like an outside landscape specialist. Someone that can say, "Well, these are the methods that you use for control erosion. This is what I do in my business." And that kind of thing. But we didn't do that. We should have done that...[it] would be a good thing to do. Also, we should have other people come in and evaluate the kids. It's not just us. Because as we were going around the room, I was really the only evaluation that I did. When I saw a cup with too much debris in it, I knew that it wasn't right. It wasn't properly conducted to read the experiment. So yeah, and I did model that. (Chris, Post-interview #5)

For both students and teachers, these integrated STEM lessons were the real problem-solving situation, not well-structured problems. They faced a lot of variations during the project and had to find solutions to the ill-structured problem. For example, the teachers did not know how long the experiment would take and what mistakes their students are likely to make. The students also did not know what elements they would need to consider during the activity such as the amount of materials or poured water. In conclusion, teachers need both physical and human resources to teach successfully integrated STEM lessons.

Students' Passive Learning Attitude

All three participating teachers pointed out that students' passive learning attitude was a barrier for implementing the PBL lessons. As the students were familiar with a teacher-centered teaching approach and a learning environment from traditional science classroom instruction, a change to student-centered instruction presented new challenges for the students. The students wanted the teachers to give more detailed instructions about how to proceed within the framework of the PBL lessons. Dan described this student's passive attitude in terms of the students' expectation to be "spoon fed", he stated:

Some of them are used to being spoon-fed, that's the way they learn their whole life. This is a new thing for them. The teachers are telling the students, you have to figure it out... Because lots of times kids would lock on the one idea and you can't remove them off that idea because they think that's the only way to do it. So, trying to get them to be risk takers, a lot of kids don't like to be risk takers, they like for you. You tell me what you want me to do and I'll do it, that's what they want. And a lot of times I will tell them, "You know my job is not to teach you, my job is really to help you help yourself. I'm a facilitator and I will do everything

I can to help you help yourself but I'm not going to do it for you." And a lot of the kids are still on the mindset that they want me to tell them the answer and they want to spin back to me but that's not what I'm looking for. (Dan, Interview #1)

However, as the integrated STEM lessons were student-centered and required students' active learning attitude and engagement, students' passive learning approach inhibited independent investigation into their lessons. Therefore, the teachers supported students to conduct their projects by themselves. Emily explained this point as follows:

They didn't know where to start. They had the directions. They had the materials, but they didn't know which way to go and another challenge was making sure they followed the directions. I know a lot of groups that just they forget to put soil as they kept trying and they're like, "Oh. Well, there's no soil coming up, boss [the teacher]." You need to put it in there, to begin with. So just following directions and then knowing even where to start. So, they looked on to others and used those other groups as mentor groups but then they get the hang of it. (Emily, Interview #2)

Emily's statement offers evidence that if the teacher scaffolds students' independent learning, the students will develop an active learning approach even if they have difficulty at the beginning of the lessons. Moreover, as students' active learning attitude is consistent with the motivation to learn and engagement in their lessons, it is significant for students to develop the active learning approach.

Designing the New Curriculum/ Instructional Strategies

Before starting to teach integrated STEM lessons, sixth-grade science teachers reached a consensus about what to teach. This consensus was reached at the first curriculum meeting of the

academic school year. The teachers created the driving question and discussed how to conduct the erosion bottle activity and what Georgia state standards would be met by the activity. However, the teachers did not have experience with long term PBL lessons, so they did not have prior knowledge of detailed instructional strategies such as how much time they would need to allocate for the designing stage, student conduct of the actual experiment, and assessment/evaluation. Even though the sixth-grade science teachers referred to Dan's previous teaching of the erosion bottle activity, he also struggled with the organization of the lessons. Dan's case implies the importance of experience in teaching the new curricula. Even though the participating teachers were experienced teachers who have more than seven years teaching experience, they had difficulty designing the new curriculum and employing appropriate instructional strategies such as time management of each step of the activity and organization of the lessons.

Moreover, as the teachers did not have detailed lessons plans or instructional materials at the beginning of the PBL lessons, it was not possible to share those materials between teachers. After some teachers taught the lessons, they shared what they did and what difficulties they met. Based on the pioneer teachers' implementation, other teachers obtained some ideas or instructional materials from them. Chris referred to the worksheet that described procedures of the erosion bottle activity from the teacher in the next classroom who taught her lesson prior to Chris. He described:

I think we're learning as a department how best do PBL. And so, we're kind of all assisting each other and but it's almost haphazard. It's not enough beforehand. And then do what we set plan and you still make adjustments there. It's almost like we just jump in and with an idea, we get going on it and then we say, "Oh

there's this missing. What did you do?" And then we'll borrow from it like I did with her [another science teacher]. It was not enough pre-planning in that particular. (Chris, Interview #2)

Chris' statement above shows the difficulties of planning the lessons. As Chris referred to other teachers' instructional materials, he also shared turbidity criteria with other teachers for evaluating the clarity of the filtered water from the erosion bottles. The teachers helped each other, but it was instant, not planned. Therefore, the teachers struggled when they had to prepare for the next lesson.

Otherwise, some teachers just tried to find solutions by themselves when they confronted the instructional challenges during their teaching. Emily had to spontaneously respond to an unexpected situation during the experiment. In this regard, Chris and Emily felt that they had difficulty organizing the PBL lessons. Emily explained,

The biggest strategy is just being organized. Knowing what's coming and how to get things organized so students can access the materials they need and the information they need to complete this. But a lot of times it was my first time doing that. "Oh, I need this. Oh, let me pull this out for you. Sure, that's a great idea. I should have thought of that." (Emily, Interview #2)

Furthermore, this lack of preparation gave teachers uncertainty about whether they were teaching correctly. The teachers described that implementing integrated STEM lessons requires additional effort including devoting more time to designing synthesized content and organizing the lessons.

Learning about Engineering Design Process

All three participating teachers perceived that their students benefited from learning about the engineering design process through integrated STEM lessons. Even though the teachers did not mention the specific term, engineering design process, they perceived the characteristics of the engineering design process in their PBL lessons: identifying problems, generating ideas, developing a model, evaluating possible solutions, optimizing the solutions, and finding final solutions.

Particularly, Dan and Emily pointed out the students use of an iterative process to find solutions through repeated trial and error. The students repeated the experiments and modified their erosion bottles to make a more effective device. Some students changed the materials put into the bottle (e.g. changing from pine tree straw to pebbles or leaves) and others changed the order or amount of materials. Emily explained students' learning about the iterative process in this way:

More than anything I wanted them just to do trial and error and figure out because I was very hands-off with that whole thing. So, if they were just able to figure out, "Okay this works but this didn't" and just to work together to come up with something. That was my main goal but with the academic side of it to figure out that different things can stop erosion or slow it down, and hopefully they would figure out that the plants would help stop the erosion. (Emily, Interview #2)

This optimization process is one of the critical characteristics of the engineering design (NRC 2009). The students tried to find the most effective solutions to meet the school's need with limited materials. The planning for the use of limited resources in order to the project within the

customer's budget is a significant feature of the engineering design process. Dan asserted the importance of planning and optimization process as follows:

I want them to understand that every building has a backbone to it, a structure to it. If you don't go out and build the building, they won't stand. And so, when you're doing a project, that's what it takes. It takes some planning, some research, some problem solving, and it takes getting along with other people to get it done... I wanted them to see beginning to end and I wanted them to learn that there are places within the process where they can make changes and correct things and fix things, and that comes from getting feedback. (Dan, Interview #2)

Dan and Emily's statements provided evidence that the students became more familiar with the engineering design process across the time span of the PBL lessons.

The teachers described how they became aware of the students' learning related to the clearness of the filtered water and how they recognized that these changes were related to the kinds and orders of materials within the erosion bottle. This means that the students learned how the design process affected their outcomes, so the significance of the systematic process of the engineering design. Chris described this point, "I think they [the students] understand generally how different things [cover materials] change the outcome."

The participating teachers acknowledged the benefits of the engineering design process because the students' implementation of the process had a specific purpose to solve the practical problem, stopping the erosion of their school environment. Dan emphasized that his students learned the importance of the process as well as their final products as follows:

I am always a hands-on teacher. I've always been my whole career, but even this is different from what I'm used to doing it because it's all about the process and

yeah, there is a project at the end that they have to have done. But it's more focused on the process and I really like that. I want them to know that I'm not just watching you to the end, I'm watching the whole process and seeing how you got here to this point... No engineer goes out and builds the building. They plan, they do the research. (Dan, Interview #2)

Emily stated her position on using engineering design in her classroom a little differently. She elaborated learning about the process by comparing with lab activities:

So, PBL lessons, there's a goal and it's moving forward and it's building gradually what we're doing. But with the lab, they're coming in and just what we talked about just yesterday is what we're doing. What we're going to talk about tomorrow is, we're applying what we did today and then that's it. With PBL, it's gradually building and they're learning along with it... Its kind of like the lab would be like, we call them dessert projects. You do the project at the end of the unit after they've learned everything. With PBL, it's built in. (Emily, Interview #2)

Emily's statement offers evidence that the PBL lessons supported students to learn along with the design process and that this learning happened across a unit that included the PBL project. She differentiated the PBL lessons from the "dessert projects" which are lab activities that confirmed learner knowledge from the previous parts of a traditional unit. This means that contrary to the demonstrated lab activities (i.e., Dan's original use of the erosion bottle activity as a demonstration), Emily perceived the PBL lessons included a process for student learning progress across the related lessons.

The Role of the Engineering Design Activities on Student Learning

In this research, the engineering design process and project-based learning (PBL) performed a significant role in student learning. The participating teachers perceived that their students gradually built products and so the students learned along with the engineering design process. As the engineering activity in the PBL lessons itself contained the learning about the engineering design process, the students gained experience with science and engineering practices naturally. This implies that the activity significantly influenced what students learned through the learning process.

Incorporating Engineering Design and Project-Based Learning (PBL)

Engineering design and PBL share many similar characteristics stemming from inherent features of teaching and learning strategies. As shown in Table 10, I summarized the characteristics of engineering design and PBL. I included characteristics of PBL identified by Krajcik and Blumenfeld (2006), while the characteristics of engineering design were extracted from a review of relevant sources including *Engineering in K-12 Education* (NRC, 2009). Krajcik and Blumenfeld (2006) presented five characteristics of project-based learning: learning with a driving question, learning through situated inquiry which processes of problem-solving, engaging in collaboration, using learning technology, and creating artifacts. The authors argued

Table 10

Characteristics of Engineering Design and Project-Based Learning

Engineering Design	Project-Based Learning
Defining a problem	Starting with a driving question
Problem-solving processes	Situated inquiry – processes of problem-solving
Teamwork and collaboration	Collaborative activities
Use of technology	Use of technology tools
Finding solutions and creating final products	Creation of artifacts

that project-based learning support students to deep understand science knowledge by actively constructing knowledge, not superficial understanding. Also, *Engineering in K-12 Education* (NRC, 2009) presented representative characteristics of engineering design: defining problems, problem-solving processes, teamwork and collaboration, use of technology, and finding solutions and creating final products. Both engineering design and PBL pursue the same learning objectives and student outcomes: developing high-order thinking abilities and increasing student engagement. In particular, the goal of project-based science is to “involve students in investigating solutions to authentic problems” (Magnusson et al., 1999, p. 100). In this study, the science teachers adopted PBL, which, from my perspective, also included characteristics of the engineering design process. Below Table 10, I discuss how these characteristics were exhibited in the teaching practices of the participating teachers.

Real-World Problem-Solving. Engineering design starts with defining problems and PBL starts with a driving question. In general, while teachers create and present a driving question for their students’ inquiry in PBL lessons, in the engineering design process students define problems that they have to solve. In this study, the teachers created the driving question “How can we stop erosion at Norton Middle School?” in their lessons. As the driving question guides all of the processes of the PBL lessons, it should be meaningful for learning science concepts and contextualized in the real world (Krajcik & Blumenfeld, 2006). The sixth-grade science teachers discussed the driving question is appropriate for applying science knowledge, the concept of erosion, to the school environment.

On the other hand, during the PBL lessons, the students defined their own problems when they had unsatisfying results of the experiment. The students wanted to obtain the cleanest water through the erosion bottle in their class, so they tried to identify problems in their initial erosion

bottle model and then modify it to have better results. In other words, the students started with the driving question and defined their own problems through the PBL lessons.

Krajcik and Blumenfeld (2006) insisted that project-based learning is based on situated learning which argues that meaningful learning occurs in the context of real-world situations. Krajcik and Blumenfeld (2006) described “the superficial understanding that results are difficult for students to generalize to new situations. When students participate in step-by-step science experiments from the textbook, they don’t learn how and where to apply these same procedures outside of the classroom” (p. 319). This description is consistent with Emily’s perspective stating, “They [students] see the purpose and application of what they've learned and then applying it to going outside and doing the same thing.”

Furthermore, one of the critical characteristics of the engineering design process is also learning with real-life problems. Most real-world problems including engineering problems are ill-structured, so both the engineering design process and PBL are useful for developing real-world problem-solving abilities. In this study, the teachers wanted to connect a real-world situation with their lessons through the driving question. Moreover, students have more interest and motivation to learn when their classroom learning connects with their life problems.

Self-Guided Learning. The engineering design process and project-based learning require students to participate in activities independently. In this study, the teachers acted as a facilitator and supported their students’ independent learning. None of the three teachers participated in their students experiment directly, but rather assisted the students by providing study guidelines or experiment materials. As engineering design and PBL lessons support self-guided and student-centered learning, the teachers had to adapt their teaching approaches due to their students’ passive learning approach. However, all three teachers tried to have their students

think independently, not answer the students' questions directly. By doing this, the teachers helped their students to develop a self-guided independent learning approach.

Teamwork and Communication Skills. Almost all tasks in the engineering profession are related to projects, so the concept of projects is familiar with engineering (Mills & Treagust, 2003). Other disciplines also require the ability to work as a team member and collaborate with colleagues in this global era. In this research, the participating teachers perceived that the students learned teamwork skills because of the group work of the PBL lessons and that peer pressure affected students' active participation in their lessons. Through debating and negotiating their ideas in a group, students learned communication skills and the reasoning process to persuade other team members. In general, engineering design activities and PBL are conducted in groups and students help each other even between groups. In this study, the students naturally established a learning community and shared their group's design process and results. They learned how to interact with others by doing the project. In other words, the students learned the social skills of teamwork and communication as well as academic skills.

Use of Technology. In general, science teachers use technology as an ancillary tool for assisting science learning such as Emily's class. Emily had the students use cell phones to upload taken pictures of the students' filtered water on the classroom website. She just used technology as a mechanical tool to support students' science learning. On the other hand, computer software can be considered a cognitive tool that assists students in developing knowledge such processes as collecting and analyzing data. Learning technology expands what students learn in the classroom and connects science ideas (Krajcik & Blumenfeld, 2006). In this study, the students in Chris' class used computer software as a cognitive tool for creating presentation materials of the final products. The students learned how to organize data and effectively express their ideas

to others using computer software. Using technology tools is important in both engineering design and PBL in that it allows students to develop diverse forms of data and models (NRC, 2009; Krajcik & Blumenfeld, 2006).

Finding Solutions and Developing Final Products. The last step of the engineering design process and PBL is creating the final product. In engineering, the final product is the purpose of the design process and should meet the client's needs within the specifications and limitations. In this study, the students built the erosion bottle with limited materials to investigate the way of stopping erosion around their school environment. In contrast, in PBL, particularly in project-based science, final artifacts are meaningful in that they help students construct knowledge and deep understanding of science concepts (Krajcik & Blumenfeld, 2006). Emily expected her students to learn about the scientific process and find solutions to stop erosion as shown in follows:

Interviewer: What did you expect your students to learn from the PBL lessons?

Emily: More than anything I wanted them just to do trial and error and figure out because I was very hands-off with that whole thing. So, if they were just able to figure out, "Okay this works but this didn't." and just to work together to come up with something. That was my main goal but with the academic side of it to figure out that different things can stop erosion or slow it down, and hopefully it would figure out that the plants would.

Interviewer: Do you think students achieved that goal?

Emily: Yes. Again, I don't know if they got to the academic part of it, but they achieved the being able to work together in trial and error and just understand the

scientific process is messy. You know, you have to try different things. They achieved that. For sure. (Emily, Interview #2)

Emily asserted that her students learned the scientific process and developed teamwork skills through trial and error. However, she did not know with certainty if the students achieved the academic goals of stopping erosion. Chris also expected his students to understand how to ground cover works to stop erosion and believed that the students achieved the learning objectives, stating,

Interviewer: Do you think your students have reached their learning goals?

Interviewee: Yes, I do. I do think that they understood the fact that if you don't have ground cover then you're going to have erosion. If you have something to stop that. And maybe some of them even knew that if you have leaves and pine straw and sticks down, you're going to have less erosion than having nothing.

(Chris, Interview #2)

Emily and Chris put their learning goals on developing teamwork skills and finding solutions to prevent soil erosion rather than understanding the scientific concept of erosion. Given this characteristic of the final products, Emily and Chris' lessons can be considered to include an aspect of the engineering design process.

The disparity between Learning about Process and Creating the Final Product

Dan's Classes. Dan asserted that an advantage of the PBL lessons was having an opportunity to watch the students' learning process, not just student outcomes. He argued that the PBL lessons were appropriate forms of instruction because his students learned about the process using PBL. In Dan's class, the students worked in seven groups and in each group used one 8 oz. water bottle and one 16.9 oz. water bottle in a group for



Figure 6. Pictures of the evaluation of the final products.

conducting the erosion activity. The students used the small bottle as their trial and error testing ground for the two class periods and built the final erosion bottle in the larger water bottle. They used any of three provided materials in the classroom such as paper towel, pebbles, or paper as ground cover for preventing soil from erosion. The student poured water into the bottle to check the effectiveness of the erosion bottles.

Effectiveness of the erosion prevention methods were judged by this rule: The greater the amount of clean water that the students got after filtering the bottle, the less erosion that happened.

In the third class, the students built the final erosion bottle as the final product based on what they had learned. Dan had the students go outside to create the second bottle, so they freely selected three materials in the area assigned by the teacher such as leaves, pine tree straws, or mulch. After coming back to the classroom, Dan collected the final water bottles from the seven groups and poured water into the bottles to evaluate the erosion bottles. As shown in Figure 6, Dan prepared a frame to put the bottles so that they could stand at the same angle and poured the same amount of water into each one. The students collected the filtered water in a beaker and



Figure 7. Students' final erosion bottles in Dan's class.

compared the clarity of the water between groups just by its appearance and did not use a specific rubric or turbidity criterion.

As the last step of the PBL lessons, Dan and his students ranked the clarity of water that came from each group bottle like a contest or tournament (see Figure 7), and the students recorded their group's ranking on a worksheet. Dan assigned student grade points to each group based on the group ranking of the results from the students' final erosion bottles.

As shown in the following quotation, Dan considered the learning process through which the students went to be important as well as the final products, but his assessment of the PBL lessons focused on the students' final products:

The one thing that's different for me is being more cognizant of the process. And I've always done that to an extent but now with STEM, I'm going to be more focused on the process and the product. If the process is good, then the product will eventually be good. So, I'm not worried about the product really, I'm worried about the process. If I take care of the process and they [students] take care of the process, then everything should be okay. (Dan, Interview #1)

Even though Dan acknowledged the importance of learning about the process, the approach to grading that he used did not assign scores based on process, but rather just the final results. In other words, there was a gap between the initial expectations expressed to the students and the actual implementation of the teaching and scoring of the PBL lessons. The quote that follows here shows his awareness of some aspects of this disparity, at least in terms of how he would change the lessons in the future. A quote used earlier in the document shares his insights when discussing challenges in assessing students' achievement, but it gave a different meaning when analyzed in terms of learning about process and creating the final products. Dan described:

If I do that again, I will have some written assessments along the way. And I think the written assessments are not necessarily going to be from me. I think they're going to be self-assessments and I want them [the students] not only to assess the little group that they might be in. The kids would be really honest especially when they're talking about themselves. You wouldn't think they would be. But a lot of times, they are a lot more critical of themselves than I ever would be... I think I would do more of that of having more self-assessments along the way. It might be something as simple as, at the end of the [class] period... giving them something and say, "What do you think you got accomplished today? What did you contribute to the project today? What is the strongest thing that you have to offer for the group?" (Dan, Interview #2)

Dan wanted to improve his PBL lessons by including a written assessment and self-assessment that provide opportunities for students to think about their work process.

On the other hand, Dan showed concerns about the final product of the PBL lessons in this way:

And yes, I'm really enjoying the process. Even though I love projects, that's a new adjustment for me too. I've got to talk myself out of worrying so much about the end product, but you know if the process is right, then the project will be right. That's the way I look at it. So, if you do the job and they do a good job during the process and I tell them that. Don't worry about the project. The project will take care of itself if your process is good. If you do what you're supposed to do along the way, don't worry about this. This will be good at the end. And that's a way of thinking about it too because they usually don't think about the process. (Dan, Interview #2)

Dan illustrated that the PBL lessons were a new instructional method, so he kept reminding himself to focus on the process rather than the final product in his teaching. It appears that even though Dan perceived the significance of the learning process, it was not reflected in his assessments.

Among the three participating teachers, Dan was the only teacher who prepared the framework for setting the same angle of the erosion bottles and conducted an evaluation by pouring water into the bottles. This means that Dan considered the conditions when he prepared for the students' activities during conducted the experiment. However, he showed limited consideration of the entire process of the PBL lessons. Dan assumed that if the process of the erosion bottle activity was right, then the final product would be good. However, Dan overlooked that there are many other components that influence the final products. For example, Dan's students used different materials when they built the erosion bottles, and this resulted in the difference in the clarity of the water. As shown in Figure 7, one group selected paper, paper

towel, and pebbles, while another group chose only natural materials such as pebbles, pine tree straws, and mulch.

The latter group thought they had to find materials from nature or use materials given by the teacher because the students built their final erosion bottle outside the classroom. Because there was no instruction on allowed materials, some students used natural materials and others used artificial materials. Typically, the artificial materials produced the more highly ranked clarity of the filtered water. As a result, even if other students conducted the same process with natural materials, they were not able to make good results in their rankings because going outside for the final bottle construction opened up their options to materials that they had not tested then this introduced all new variables.

Chris' Lessons. Chris' biggest concern related to the PBL lessons was the final product. The students in Chris' class created Google slides to present their ideas and the procedures of the erosion bottle activity. Chris thought that Google slides were the final products of the PBL lessons and concentrated on helping students to create the slides. He had difficulty teaching how to use Google software because most of his students did not have experience with the computer software Google slides and Dropbox. Chris wanted his students to use these technologies for the final products, but it took more time and effort than expected. Chris illustrated this difficulty as follows:

The final product was the biggest problem...I'll tell you this, the most challenging part of it so far for me has been getting them to do the final product which is a simple thing. It's the Google slides, okay? And many of them lack the skill to put that together. It almost didn't work, but I almost can't believe that they don't know how to do that... But I'm not going to really hold them to it. It's too much because

I need to move on. See, we're starting a whole new unit Monday and I'm not going to drag this out. On Friday we'll go to the computer lab. Finish out that part of it. And I have another thing that I want them to work on in the computer lab which is the Dropbox activity. They don't know how to put things in a Dropbox.

(Chris, Interview #2)

However, from this researcher's perspective, the students' actual final products were presentations. Chris held a student conference to give his students opportunities to present their proposals and invited a diverse audience including the school's principal, assistant principal, and policymakers of the state government. Chris helped his students to write their proposals that included students' ideas and the procedures for finding solutions to stop erosion at the middle school. At the conference, there were tables for each student group, and members of the audience walked around the tables to listen to the presentations which were happening concurrently. After listening to each group's presentation, the audience members gave feedback to the students. As the students repeated their presentations to different audience members, they gained more

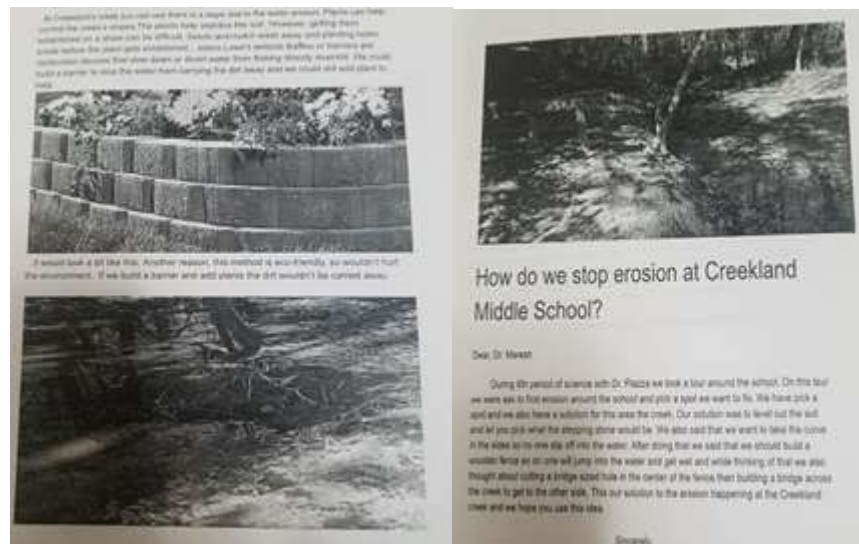


Figure 8. Examples of the students' proposals for presentations.

confidence in their work and presentations. Through the presentations and the preparation made prior to giving them, the students learned how to express their ideas in different forms including written form, PowerPoint, and oral presentations (see Figure 8).

Furthermore, after finishing the erosion bottle activity, Chris had students write reasons on their worksheets for why they selected the particular materials and suggestions to solve the driving question (how to stop erosion at NMS) as well as results of their particular experiment (see Figure 9). Chris assessed students' writing on the worksheets when he evaluated students' achievement of the PBL lessons.

Moreover, Chris' PBL lessons were different from other teachers in that his students conducted both individual and group experiments. Having students work individually and in groups to create their erosion bottles was planned in the curriculum meeting, and Chris taught based on the plan while other participants did not. In his classes on the initial day for creating erosion bottles, each student built an individual erosion bottle and evaluated the bottle by pouring water into it. In the next class, the students split up into groups and discussed how to

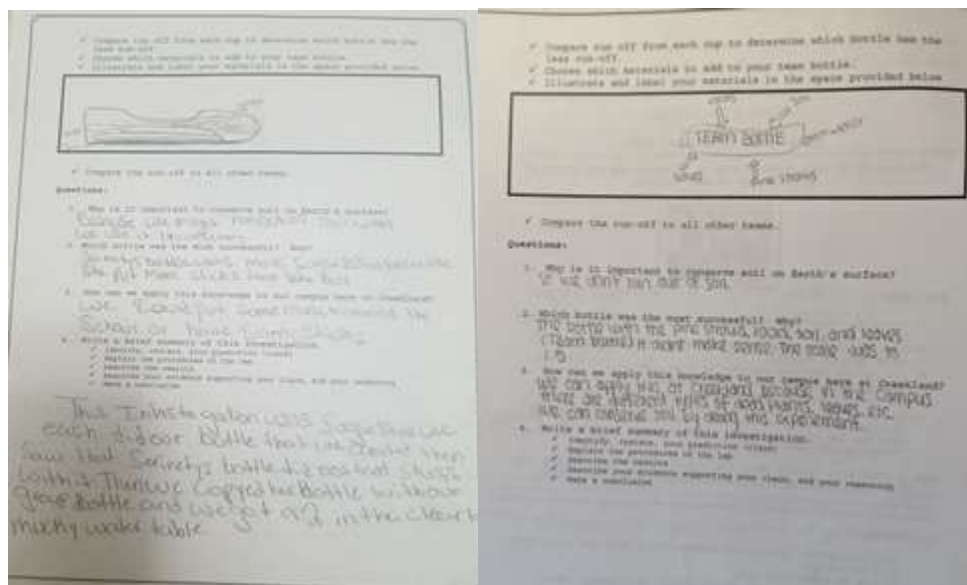


Figure 9. Examples of the students' worksheets.

build their group erosion bottle based on the results of the personal experimentation. In other words, the students collected data from their independent work and analyzed and used the data for the group work. Through this repeated process, students learned about working independently and as a team member as well as about the iterative engineering design processes. In addition, Chris and his students walked around the school environment to decide the target location of the presentations in the fourth PBL class. Some students decided to cover the river bank and others wanted to protect a garden area near the school building. This experience helped the students specify their ideas when they prepared the conference presentations. Furthermore, it helped them to connect learning in the classroom to the real-world application.

Chris perceived that it is important to teach the creation of the final products and expressed difficulties in guiding students to do it. However, his actual teaching was concentrated on the whole learning processes rather than the final products. Also, his assessment of student achievement included the engineering design process as well as the final products. It is important to note that Chris did not have a science background and that he had been teaching earth science in a general setting for 2 years at the time of the study. In order to complement the lack of experience in teaching science, he tried to prepare his lessons in detail, participated in professional development programs for PBL, and referred to other science teachers' lessons. For example, he searched and provided turbidity criterion (see Figure 10) for his students to measure the clarity of the filtered water. Even though Chris did not intend to focus on teaching of learning processes, his prepared lessons led the students to learn about science and engineering processes.

Emily's Lessons. Emily's teaching of the PBL lessons was consistent with the curriculum team goals. Emily wanted her students to learn about the processes of scientists' work. She said, "More than anything I wanted them just to do trial and error

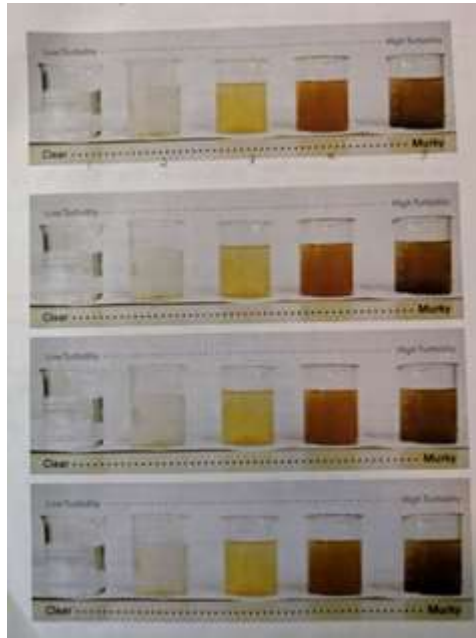


Figure 10. Turbidity criterion that Chris provided for his students to evaluate clarity.

and figure out [the methods of how to stop erosion].” Her approach is a fit with the that of engineering design as discussed in the previous section.

Although Emily allocated the shortest time for the PBL lessons (three class periods) among the three participants, she had time for both the activity and discussion. Emily conducted the experiment (i.e., students creating erosion bottles) for two class periods and had a class discussion about the project and results in the third class of the PBL lessons. She rearranged the schedule to have two consecutive class periods for conducting the erosion bottle activity. This long class time was beneficial for both students and the teacher because they focused on the activity without interruption. The students conducted the activity in groups with one water bottle. If they were not satisfied with the results of the experiment, they washed the bottle and repeated the activity with the modified models (see Figure 11). At the end of the second-class period, the students took pictures of filtered water and uploaded them on the class website.



Figure 11. A picture of students' work in Emily's class.

In the third class of the PBL lessons, Emily and her students evaluated the pictures of the final results to decide which group's erosion bottle was the most effective. During this evaluation, the students debated the correct procedures of the project. Some students argued that the winning group did not perform a fair experiment procedure because the group did not put the right amount of soil in their water bottle. Emily let her students freely discuss the project, and her students focused on what the correct processes of the activity were. As Emily described her role as a facilitator, she did not make a judgment on the activity. She illustrated her role as a teacher in this way:

I can go to each group and I can just ask them questions and they can come to learn on their own. I don't know what that's called. That would be the facilitator.

Okay yeah. I'm definitely more of a facilitator than just a teacher and student because in my science classroom, I try to have the students as the center of

everything. They're guiding the learning and I'm just "Here you go." (Emily, Interview #2)

The efficiency of her allocation of time may have also limited the opportunities for learning. Emily and her students did not talk about their ideas and solutions to the driving question. They did not discuss why particular materials worked to stop erosion and how to prevent the soil in the school environment from eroding. Also, Emily evaluated student achievement by asking questions on the worksheets focusing on vocabulary including the experimental procedures and results. Emily planned to improve her PBL lessons in the future by giving the students opportunities to present their ideas and suggestions. Emily reflected on her lessons and described that the final products of the project can change in future lessons. She said:

Knowing how to organize it [the PBL lessons] and then you just don't know what you're going to learn until you do it, so I think as long as you have everything organized...[then] they understand the application of the skill. Like I should have taken this one step further like Chris did instead of just ending it with that [pictures of the clarity of filtered water] because that was the end of the time that I had but [the lesson would have been improved if the students had taken] it further and having them develop their ideas and what they figured out during the project.

(Emily, Interview #2)

Emily's PBL lessons were self-guided and student-centered because the students investigated their project independently and Emily assisted them. However, she wanted to strengthen her teaching related to the final products. To this end, creating a more detailed overall plan that includes more about the final product but also allocating more time for them to work toward that final products.

Influences on the Components of Science Teachers' Pedagogical Content Knowledge (PCK)

In this section, I discuss the influences on the components of teachers' pedagogical content knowledge (PCK) that emerged from the data analysis of their implementation of the PBL lessons. Three themes of the findings are: (a) The teachers' existing knowledge of instructional strategies for teaching PBL was a dominant component of their knowledge of teaching science that influenced other components of PCK, particularly knowledge of orientations to teaching science and knowledge of assessment of student learning; (b) the teachers' knowledge of instructional strategies for teaching science influenced how they conceptualized their knowledge of assessment of student outcomes through conducting the PBL lessons; and (c) the teachers' knowledge of students' understanding influenced their knowledge of instructional strategies as well as their knowledge of curriculum.

As the development of teachers' PCK is understood in the context of teaching a specific subject (Sanders, Borko, & Lockard, 1993; Tamir, 1988), the reader should refer back to the details of the context of this study if needed (see page 41). But one critical element of that context is the idea that the three participant teachers were all science teachers. The six components of PCK of the hexagon model (Park & Oliver, 2008b) were grounded in teaching *science*, for example, orientations to teaching *science*. In this study, I investigated teachers' PCK in the context of implementing the PBL lessons which were designed as an entry point for what will ultimately be teaching integrated STEM curricula, not single-subject science. Therefore, this discussion of PCK examines how I explored each component of PCK based on teaching PBL lessons content.

Interaction among Knowledge of Instructional Strategies, Knowledge of Assessment, and Orientations to Teaching

In general, teachers' orientations to teaching science work as a conceptual map and influence teachers' implementation of instructional strategies and thus their actual teaching practices (Magnusson et al., 1999; Park & Oliver, 2008b). However, this study is not specifically about the teaching of science because the teachers had to implement the PBL lessons which had a science base but also included aspects of integrated STEM. In this study, teachers' perceptions of what is required to implement PBL powerfully shaped teachers' orientation to project-based instruction based on the nine orientations by Magnusson et al. (1999). The PBL approach as emphasized within team meetings and by school administration acted as the compass and influenced comprehensive teaching of the participating teachers.

As introduced in the literature review, I adopted the categorization of the nine orientations to teaching science by Magnusson et al. (1999) to investigate influences between orientations and other components of PCK. These nine orientations are: process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry. Each of the participating teachers implemented instruction that was evidence of two or more orientations. And in each case one of these orientations was project-based science orientation.

Dan's orientations to teaching science and PBL. Dan exhibited combined orientations of process, activity-driven, and guided inquiry in addition to project-based science based on observations of his teaching and interviews. Even though *project-based science* was the dominant orientation, he also focused on teaching thinking processes throughout the project. The goal of a *process* orientation is to help students learn the scientific thinking process skills

(Magnusson et al., 1999). In particular, Dan helped the students to develop scientific thinking abilities such as problem-solving abilities. Also, Dan's classes, based on his description of teaching prior to the implementation of the PBL approach, included many hands-on activities for a demonstration of science concepts or discovery and was thus representative of an *activity-driven* orientation.

Furthermore, Dan, at times during his instruction, implemented an approach that had characteristics of a *guided inquiry* orientation that focused on building a learning community within the student members of his classroom. His hands-on activities and the PBL lessons were conducted in a group. He thought of his role in his classroom as a facilitator and so assisted students' independent learning which included choosing not to give direct answers. Dan emphasized creating a community-centered learning environment and wanted his students to teach, learn, and evaluate each other. He believed that peer pressure assists students to take responsibility for their group work and develops social skills among group members by getting feedback from peers.

On the other hand, experiences teaching the integrated lessons influenced Dan's knowledge of instructional strategies and also his knowledge of orientations. As stated previously, Dan enjoyed teaching with group activities, but he managed his classroom strictly. He wanted his students to conduct the activities within expected boundaries. For example, Dan gave specific instructions on worksheets that the students should follow. However, Dan's belief was that the PBL lessons required allowing the students to explore freely, so he will allow more freedom for his students to make mistakes in his future classes. Dan reflected on his STEM teaching and planned his future lessons:

I still need to work on organization and for all this time, you know, I organized to a big degree but with STEM it's even going to be more extreme so being able to manage all of it. It's almost like juggling, you know, it's like a circus going on all the time. And in some ways [I am] some kind of control freak... I think I'm going to have to let go a little bit of that and still be sure that I get done what needs to be done. The kids are doing what they should be doing but I need to give them a little freedom to explore and to make some mistakes. Because they will make some mistakes. So, I'll say, yeah, that's organization is going to be a little bit of a problem for me. I don't think the mindset of STEM is very much different than what I do already but I'm going to have to tweak it, that's for sure. (Dan, Interview #1)

Dan mentioned the difficulty of the organization when he taught the PBL lessons, but he wanted to change his instructional strategies to be a more student-centered learning approach. He described that he needs new approaches to teaching within the PBL lessons. Moreover, Dan considered changes in the last part of the PBL lessons. He said:

I might have asked them questions about what they can possibly do, but having them do it themselves, and problem solve it themselves is a completely different ball game. The other extension of that is not only coming up with a solution but taking it even to the next level. That's something else I would do next year too. I want to take it to the next level where we actually, physically try to solve a problem on campus, where we actually go get some straw or some stuff and try to fix the place, you know that they decide that's being a problem. (Dan, Interview #2)

He wanted to modify his lessons so that students could have direct experiences of problem-solving in real life beyond finding solutions in the classroom. Without using the terminology of PCK, Dan described the experience of teaching the PBL lessons as an influence to be more student-centered and to create instructional sessions that guide students' independent learning. Therefore, he felt that his knowledge about orientations changed during the entire period encapsulated by the PBL lessons.

Furthermore, Dan's knowledge of instructional strategies and knowledge of assessment of student learning were improved through teaching the PBL lessons. His experiences guided the project-based approach for his students and how to assess student outcomes of the PBL lessons. More specifically, his assessment on the worksheets included grading the clarity of the filtered water after passing through the erosion bottle and simple questions for the students about the experimental procedures. As described earlier, Dan wanted to develop diverse assessment methods such as written self-assessment for future lessons to provide further opportunities for his students to reflect on their own work. A quote used earlier in the document shares his insights when discussing challenges in assessing students' achievement, but when analyzed using the different framework of PCK for the analysis, it gave a different meaning in terms of PCK:

I've done this demonstration before but never done it with the kids before, so I was kind of in the dark of how long it will take, those kinds of things. I've been through it now so now I know. So that in the future, I can account for that, make adjustments for that... If I do that again, I will have some written assessments along the way. And I think the written assessments are not necessarily going to be from me. I think they're going to be self-assessments and I want them to, I want them not only to assess the little group that they might be in, but the kids would

also be really honest especially when they're talking about themselves. (Dan, Post-interview #4)

In this respect, Dan's orientations interacted with his instructional teaching strategies and helped his development of knowledge of assessment of teaching PBL lessons.

Emily's orientations to teaching science and PBL. Emily's teaching and responses to interview questions exhibited *inquiry*, *didactic* and *project-based science* orientations to teaching based on the nine orientations by Magnusson et al. (1999). Most of Emily's lessons were student-centered, and she performed as a facilitator in her classroom rather than giving direct instruction to the students. Emily's *inquiry* orientation influenced her teaching by guiding students to investigate science problems and make conclusions properly. For example, when she taught weathering and erosion, she prepared six stations for the students to investigate natural phenomena related to weathering and erosion. She listened to students' opinions regarding why they thought of a particular phenomenon as weathering and discussed the phenomenon in detail when the students said wrong answers.

Also, Emily wanted her students to know that science exists all around us and for them to know the joy of learning science. To this end, she thought students need to learn scientific subject matter content first, so her lesson included lecture and discussion to teach science knowledge. This instructional strategy reflected on her *didactic* orientation, which was a primary feature of her teaching. In particular, she concentrated on teaching vocabulary to strengthen students' lack of science knowledge. Therefore, she possessed and used both *inquiry* and *didactic* orientations to science teaching. Emily explained her orientations as follows:

It [science] is life. Science is when you walk out the door. Science is sitting in this chair and what's going on in the world and in your life is because of science. And

relate it back to technology, like the phone that you have, even riding the roller coasters at Six Flags, it's all because of science. If you don't understand science, you don't care about science, because you're choosing not to participate. It's fun, it's interesting. It explains everything. I want to get them to be as excited as I get, but I'm working on that. (Emily, Interview #2)

In this study, Emily facilitated the PBL lessons with her knowledge of the *project-based science* orientation. Her stated orientations were consistent with her instructional strategies. She assisted the students' erosion bottle experiment by preparing three cover materials – mulch, pine tree straw, and pebbles – and rearranged the class schedule not to interrupt her students' investigation. Emily allocated two consecutive class periods by switching the class period with another teacher. She wanted her students to focus on their project without being disturbed by the short class time period. She described,

I connected two classes because I want to give them enough time for conducting the activity. I switched my Monday's class with her [another teacher]. Students often forget what they did in the previous class, so I want to let them finish their work today. (Emily, Post-interview, #3)

Furthermore, the experience of teaching within the overall goal of PBL developed Emily's knowledge of instructional strategies. Emily initially had difficulty organizing the PBL lessons. To make this point, the same quote from Emily from earlier in the document when I discussed challenges for implementing the PBL lessons is used here. But in this usage, the analysis was done using codes derived from the PCK framework. Emily said:

I think the biggest strategy is just being organized. Knowing what's coming and how to get things organized so students can access the materials they need and the

information they need to complete this. But a lot of times it was my first time doing that. "Oh, I need this. Oh, let me pull this out for you. Sure, that's a great idea." I should have thought of that. (Emily, Interview #2)

However, it became clear that Emily had learned how to manage and instruct the PBL lessons and had even planned improvement of instructional strategies for future lessons. The following quote shows some aspects of what Emily learned through implementing the PBL lessons and also aspects of what she considered necessary to improve:

I think I would have them [the students] do it individually or with just one partner versus three or four in a group. So, they can work better together versus just "Okay. Well, you are getting the materials." Some students, that's all they did was just get materials. They didn't participate in the thinking, but having more bottles they can do it with one other person and then extending it further, so they see the purpose and application to realize rather than applying what they've learned to a bottle then applying it to going outside and doing the same thing... I should have taken this one step further as Chris did instead of just ending it with that because that was the end of the time that I had but taking it further and having them develop their ideas and what they figured out during the project. (Emily, Interview #2)

Emily considered that an individual or smaller group activity would be more effective for her students based on her observation of the erosion bottle activity. Also, she wanted to add the final step to help students develop their ideas and find solutions for the project. In this respect, the teaching experience of PBL influenced Emily's knowledge of instructional strategies as well as orientation to teaching.

In addition, her knowledge of assessment was also developed through PBL lessons. Emily created assessment materials of the PBL lessons including vocabulary assessment and written questions through which students would provide an explanation of the project procedures and analysis of the results. Moreover, as Emily observed students' work and the experimental procedures, she learned what students achieved through PBL lessons such as trial and error processes.

Chris' orientations to teaching science and PBL. Chris exhibited knowledge of orientations of *project-based science* and *guided inquiry*. He emphasized developing teamwork skills through his whole class activities of both PBL and ordinary classes. Chris' guided inquiry orientation was consistent with his instructional strategies and influenced his comprehensive teaching practice. Almost all lessons taught by Chris featured group work and students helped each other as a learning community when they conducted the erosion bottle activity and other activities. Chris described this as follows:

I try to teach them basic skills, and what I have in my room is teamwork. So, they have to work as a group, and they have to have little roles like there'll be a materials manager at their table and a team leader. I think it builds them more than just in science. It teaches them a sense of teamwork as I've said and expression, verbal expression, written expression, problem-solving. They have to work together to come up with solutions in time or see what the outcome really means. They like it. They like coming here. (Chris, Interview #1)

This quotation illustrates how Chris focused on teaching and learning teamwork skills and helping students learn through working in groups. His knowledge of this instructional strategy is

quite detailed and allows him to express specific benefits that the students will gain from learning within that form of teaching.

On the other hand, among participating teachers, different levels knowledge of instructional strategies related to PBL resulted in decisions to seek different final artifacts from students, and this change of which products were sought reflects how knowledge of instructional strategies for these teachers was connected to knowledge of assessment methods. Chris had PBL training and was aware of the characteristics of the PBL lessons. He used his knowledge to create a final student product requirement that had them creating Google Slides of various aspects of the erosion bottle activity. This approach assessed students' achievement by examining their proposals for presenting the results of their work.

While Chris considered evaluating the clarity of filtered water as a means to assess student outcomes and process thinking resulting from the project, Dan and Emily thought the clarity of the water was an important final product of PBL lessons. Chris took this a step further and assessed students' proposals that included their ideas and organizing skills. After conducting the erosion bottle activity within the context of the PBL lessons, Dan and Emily each stated a desire to improve their assessment methods by adding more diverse assessment strategies such as written self-evaluation or modifying the final products required of students, as I discussed above. In other words, teachers' knowledge of assessment was strengthened by the knowledge of instructional strategy through implementing PBL lessons. **Impacts of Knowledge of**

Instructional Strategies for Teaching Science on Student Learning of Ancillary Enablers

As was discussed in the previous segment, the participating science teachers' knowledge of instructional strategies influenced the teachers' knowledge of assessment of PBL, specifically assessment methods and recognition of the need to maintain a knowledge of student outcomes.

As a result, the teachers' knowledge of instructional strategies influenced student learning of outcomes that were enablers of their learning but not the primary goal. The participating teachers employed the project-based learning approach as a way of implementing an early version of integrated STEM curricula, so project-based learning is the overarching approach to the instructional strategies used in this study. The driving question which framed this overarching approach was "How can erosion at the middle school building be stopped?"

Driving questions play significant roles in project-based learning, specifically organizing and guiding the project, as well as providing a real-world connection. Krajcik and Blumenfeld (2006) described the role of driving questions as follows: "As students pursue solutions to the driving question, they develop meaningful understandings of key scientific concepts, principles, and practices" (p. 321). Even though the participating science teachers created the driving question, the students and teachers placed primary focus on creating a set of instructional sessions that would lead students to create a product (i.e., constructing the erosion bottle), rather than finding solutions to the driving question. The teachers introduced the driving question at the beginning of the PBL lessons, but they did not facilitate students to pursue an answer to the question through the PBL lessons. Chris mentioned the driving question at the end of the PBL lessons as a means for helping students with creating proposals for the presentation of the workshop.

Furthermore, Chris had his students use the computer when the students prepared proposals for presentation. The students created Google Slides for the presentation and used Dropbox for sharing information among their team members. As most of the students did not have experience with these two software applications, the technology created instructional difficulties for Chris and he had to spend, unexpectedly, two more class periods to teach them.

Even though Chris struggled with teaching students to use the necessary computer software to complete the lesson as planned, the students created their proposal materials using technology. As a result, they learned how to present their ideas effectively with diverse media formats. Thus, these actions by the students to figure out how to use the necessary technology made the lesson an even stronger example of STEM than was intended by the teachers. Using the technology was an ancillary feature, but yet their use broadened the impact of the PBL lesson. Krajcik and Blumenfeld (2006) emphasized the value of using technology: “Learning technologies allow students to extend what they can do in the classroom and serve as powerful cognitive tools that help teachers foster inquiry and student learning” (p. 316). In this particular instance, the presence of a need for student use of technology even in the absence of teachers’ knowledge of instructional strategies necessary for teaching students to use technology influenced the student learning outcomes. Likewise, even though the teachers did not emphasize the driving questions until the end of the unit, the presence of that question did give focus for the students which appeared in the form of summaries for presentation or for sharing.

The Impact of Knowledge of Students’ Understanding of Science on Knowledge of Instructional Strategies and Knowledge of Curriculum

As students exhibit different developmental levels and learning approaches, teachers’ instructional strategies change based on teachers’ understanding of students’ learning needs. Dan was an experienced teacher who had been teaching 28 years at the time of the study. However, as he mostly taught gifted classes, he had difficulty teaching classes at a different level. Dan said, “I don’t understand why they don’t understand it.” Dan’s limited knowledge of students’ understanding influenced his instructional strategies. Dan thought the teacher’s role that of a facilitator, not a lecturer, but when he taught standard classes, his instructional strategies were

adjusted to be teacher-centered and in lecture style. As a result, Dan showed the didactic orientation in addition to the process, activity-driven, and guided inquiry when he taught the PBL lessons of the standard classes. He elucidates his changed instructional strategies as follows:

You have to break it down into small chunks. You know, you have to make sure they [students in standard classes] understand this before you move on to something else. And you have to watch your pace. Like I said, you have to be repetitive. You have to always repeat things that you've done before to try. (Dan, Interview #1)

Dan also described his perspectives on the students in standard classes compared to the gifted students. He said,

With the gifted kids, I don't have to worry about that too much because I know they get it, they learn fast, they catch up fast and they'll understand it fast and they can't get wrong with it. But with the other students, that's something that you have to be conscious of all the time, check their understanding. And I'm still learning that lesson because there are times I get carried away. I taught nothing but gifted kids for so many years. I'm used to kids learning quickly and moving on and going fast. And this year, there were two standard kids, I have to catch myself all the time that you know, they're not getting as quickly, we have to slow down, we have to check on their understanding. So, it's a constant thing...I keep reminding myself all the time. It's constant, constant, constant checking on their understanding. (Dan, Interview #2).

Dan's knowledge of students' understanding mainly consisted of teaching gifted students, so he was learning about students' learning in standard classes and adjusted instructional

strategies based on the students' understanding.

On the other hand, Emily mentioned that she was not sure if she taught everything that she had to go through the PBL lessons. This uncertainty influenced her knowledge of curriculum. I used the same quotation below with a discussion of the teachers' challenges in the previous section. However, this quotation implies different meanings in terms of the teacher's knowledge of students' understanding and knowledge of curriculum. Emily stated:

Well with that, it was mostly just observation because since this is my first time and their first time, I did not know what to expect. So as long as they came up with and I assisted through them posting their pictures of their followers and then have the kids compare with each other. But I mean I didn't do a formal assessment with anyone... I feel like I'm going to miss something, or I won't have time for that. It could go on forever. Or am I really teaching them exactly what they need to know by doing this one activity? So, it's a little stressful and I'm a little hesitant as we go further into it. (Emily, Interview #2)

As Emily did not know if her students achieved what they were supposed to learn, she was not able to organize the lessons in terms of the content she had to teach.

Chris majored in special education and had taught students in special education classes for several years. He had been teaching science for two years at the time of the study and according to his own comments given that his background was not in science, he had little confidence teaching science. He paid attention to students' understanding of science and tried to learn instructional strategies from other science teachers. Another aspect of Chris' lack of experience was that he carefully observed students' activities and their work in order to complement his knowledge of students' understanding of science. He also preferred group

activities in his class. He arranged the students to have a specific role to contribute to the group's achievement and helped each other through peer teaching strategies. By doing this, Chris supported the students to develop teamwork skills as well as academic skills.

In this section, the influences on the components of the teachers' PCK throughout implementing the PBL lessons were discussed. The participating teachers' knowledge of instructional strategies for teaching PBL influenced knowledge of orientations to teaching science and knowledge of assessment of student learning. Moreover, the teachers' knowledge of students' understanding influenced their knowledge of instructional strategies and knowledge of curriculum. The PBL approach influenced the participating teachers' comprehensive teaching and their PCK.

Administrator's Perspectives on Integrated STEM Education

In this section, I discuss my analysis of an administrator's perspectives on implementing integrated STEM lessons and PBL because this analysis can provide different ideas for overcoming obstacles for implementing integrated lessons in school. The assistant principal, James (pseudonym), was an experienced science teacher who taught science for eight years and had been working as an assistant principal for six years at the time of the study. He encouraged teachers to begin the process of implementing integrated STEM lessons through the PBL lessons as an introductory level. He called this STEM PBL. I basically asked James the same questions that I asked the participating science teachers for investigating similarities and differences between their perspectives on integrated STEM education.

In response to the question about the definition of integrated STEM education, James exhibited a general approach to STEM education that focuses on the benefits of integrated STEM

education: developing a practical application, problem-solving abilities and collaboration with others through teaching integrated STEM subjects. James said:

STEM education is finding natural and practical applications in math and science, finding places where they overlap, understanding the natural connections between science and math and teaching through that lens, providing kids with relevant learning experiences. I believe kids can learn through those relative experiences, that learning is not memorizing material, that it's working through problems, it's working with others, working with your peers and doing that with technology, not just being consumers but using technology to produce our products. Of course, googling things is not going to be a job in the future but using technology to make products and to make communications and things like that. So, I think it adds to being or it becomes a way that you view science and math and it's a way of thinking with a focus on application and the focus on collaboration. (James, Interview #1)

James perceived that integrated STEM education, and its precursor of PBL, was a useful approach for students to develop teamwork skills and to provide learning experiences in STEM fields. In this regard, his statements were similar to the teachers. Differences emerge in his answers to additional questions.

The Reasons for Promoting the PBL Lessons

Starting with a Baby Step. James understood that experienced teachers had difficulties with trying to teach the new curricula or new instructional strategies. In particular, he was clear that when school stakeholders think of the concept of integrated STEM education, it places on teachers the burden to create fully integrated lessons of four disciplines. Therefore, James

wanted to start with a small change to transit toward integrated STEM education. He explained that once teachers experience success with a few changes such as working with a student or giving diverse options for final products, then teachers can implement bigger changes. James explained:

We have a number of teachers who have been here for all 21 years that Norton Middle School has been here. So, there's not typically a lot of turnovers and so there's a lot of people that are great people and great teachers but haven't really thought through teaching the curriculum in that manner of the integration of science and math. Now it kind of gets back to the original middle school idea, that's the whole point of middle school and that's why we have connections and I mean, so it really shouldn't be that far out of the box for a lot of people. But we wanted it to be or I wanted it to be something that people could have something that they could really hold on to, they could research, they could look up ideas and things like that. And I just felt like that the project base hit a couple of things. Number one, it would help us to if we had a bigger goal of integrating our projects across the curriculum, it would naturally lend itself towards the science and math integration and to focus on science and math together. (James, Interview #1)

When it comes to the inflexible school environment, it is difficult to transit from traditional learning to integrated STEM curricula at once. James and the other administrators made a decision to adopt project-based learning as a method to learn about the impact of teaching that had traditionally been single subject science in the form of integrated STEM education. He

thought that PBL included a lot of components of STEM education, such as integration of science and mathematics. He said:

It's allowing that learning through which I think embodies a lot of the spirit of what STEM should be... what STEM learning should be, that experiential learning. (James, Interview #1)

This quotation supports the idea that James and the other administrators felt that they were on a path toward a goal of having students learn within a true STEM curriculum that emphasizes subject matter integration, independent work that is related to practical encounters with science in life.

Providing personalized learning. In James description, the Norton Middle School confronted a difficult environment that had diminished levels of support from the family for students' learning. He perceived that the school should consider students' background to provide appropriate educational support connecting student learning with their lives. James explained this difficulty that the school faced:

We've faced some challenges where we have parents that are working in different schedules and we have kids that go home to empty houses until nine o'clock at night and so we don't necessarily have a strong parental background or support network as we did before. And so really, we know that the learning is what happens here at school and we've got to provide those relevant learning experiences. (James, Interview #1)

Moreover, James' orientations to teaching influenced his administrative work, for example, designing the new curricula and promoting the new instructional strategies. He perceived that school should provide personalized learning for students considering individual

differences. Furthermore, he thought that school should help students develop academic and social skills, such as teamwork skill for preparing students' future careers. James thought the school should meet the needs of society and that PBL is an effective method for students to have opportunities to contribute to the local community. For these reasons, James encouraged teachers to enact the PBL lessons as a first step toward integrated STEM education. He pointed out the importance of implementing PBL in terms of providing personalized learning for students as follows:

I think my goal would be standards-based grading and true project-based learning, personalized learning, I know that that's probably a few steps past where we will get any time in the near future. And so, I feel our STEM PBL initiative is kind of a first step in the right direction towards that... I think our STEM PBL is the first step in valuing what I think really matters and those are skills that our students have to work together. They have to work on a team. They have to be able to look at a situation, come up with a solution, get feedback, act on that feedback, think differently than they have ever thought, do more than memorize, use your technology resources for what they are, and hopefully begin to be developers of technology and developers of products with the technology, and again designing those solutions... What I really liked about it because it was meaningful and education is being able to assess where you are, what the needs of your students are, what the needs of your community are and really going at it like that. (James, Interview #1)

Availability of Resources. James also considered the school's availability of resources. As an administrator, James had to take into account what resources the school can use or obtain

from the school district. As the school district provided the resources for PBL such as a PBL training program for teachers, James decided to implement the PBL lessons as a transition to teaching STEM curricula. He stated,

I think also, PBL is something that our district, which is a very large district has some supports in place and it was something that would really. It would be something that I could draw on support from our county office as it wouldn't be 100% locally driven. Like I could use those resources and our county does look at STEM and PBL as you know, not the same thing. I mean obviously, but we really viewed the STEM through that. So, I think the availability of resources. (James, Interview #1)

Challenges for Implementing the PBL Lessons

Changing School Culture. James thought that the biggest challenge for implementing the PBL lessons was changing inflexible school culture. Since 90% of the teachers at NMS had teaching experience over 6 years in 2017, James perceived that it is difficult to encourage teachers to try to the new teaching approach. He wanted teachers to feel comfortable trying to teach new things. James said:

For me, I'm trying to develop a culture of that's okay. I even asked, when I went to evaluate them for their major evaluation this year. If you're doing something new or STEM PBL based, I would love to come to see that. Because I want them to know it's okay if it's not the best lesson you've ever thought you know, you're not going to have a tanked evaluation. And I think that's hard for people to feel. They want you to see them as excellent. They want the best rating and so I think to help them to trust that I value trying new things more than I value you know, a

perfectly planned thing that you've done forty times. That's a trust that you have to build, and I think that's hard and I'm learning too that I've got to be in there with them planning it. especially here at the beginning and I've got be able to laugh at the times we've messed up and say, we're really dumb. I can't believe we didn't think of that. That's been a challenge. (James, Interview #2)

As an administrator, James focused on making the open environment for teachers rather than preparing practical materials. He made an effort to make teachers feel comfortable when the teachers try new instructional strategies without worries about the evaluation of teachings. To this end, he actively participated in the curriculum meetings for PBL and discussed any difficulties with teachers to support them.

Supporting Teachers. James believed that sixth-grade science teachers are excited about implementing the PBL lessons. To better support the teachers, James wanted to suggest a vision for teaching integrated STEM lessons and provide opportunities for teachers to see actual examples of other schools' implementation or have the new insight through participating in the STEM conferences or professional development programs. As James had to consider financial limitations, he had difficulty supporting teachers in those ways. James also understood teachers' difficulties in designing a new curriculum for teaching STEM PBL lessons. He perceived that one of the hardest parts is how to teach to make the lessons meaningful and how to assess student achievement. He emphasized that because the school's evaluation is test score-driven, it is difficult to assess student outcomes through STEM PBL lessons and this can be an obstacle to make sure the effectiveness of the new STEM curricula.

James thought the middle school can easily get help from experts because his school county has enough human resources for STEM education: a new science director and math and

science coaches who can integrate math and science content for integrated STEM lessons. Moreover, the school county provided PBL training and the middle school had a STEM coordinator who leads teachers' preparation for teaching PBL lessons. He elucidated these resources as follows:

Our county offers PBL training and so they've come up with their own PBL framework and we have...a STEM coordinator who also leads us PBL lessons at our district office...It's allowing that learning through which I think embodies a lot of the spirit of what STEM should be. What STEM learning should be, that experiential learning. So, we have those training at the county office and then we do have our STEM coordinator. They offer, she offers I want to say was four times, basically monthly each semester. You know, either night or Saturdays where there are basically opportunities for teachers from local schools to come together and share best practices or share what they've been working on. (James, Interview #1)

However, the teachers showed perspectives different from James regarding school resources and professional development. Emily mentioned about the practical issues for participating in the PBL training. She was not able to join the PBL training because participants were not paid for their attendance, and it happened in the evening after school. Financial issues and limited time are critical for teachers to participate in professional development programs.

Emily mentioned,

The county offers it, but it's extensive like there are six days over the summer and it was not paid. And then there are times over the school year, but it's after school. So, those things I can never go to because I can't I mean, I have a family, too. So,

we've been playing around with little pieces of it. But, as far as doing our first large-scale PBL, we're in the planning stages. (Emily, Interview #1)

Also, Chris presented the need for experts who have a specialty in areas in which the teachers are not able to cover such as geology experts.

On the other hand, James and the three participating teachers agreed that technology and engineering are challengeable areas to include them in the integrated lessons. For example, as discussed in the previous section, Chris had difficulty teaching the use of computer software and needed support for teaching technology. Also, as the middle school had only one engineering teacher, the science teachers get help from the engineering teacher when they planned the integrated STEM lessons. James described this difficulty as follows:

I will say that [engineering] and/or technology are the two areas where I think we need, or I need, our school needs, our teachers need the most support maybe development, and how do we get those engineering principles in there. (James, Interview #2)

Achievement through Implementing the PBL Lessons

James perceived that the most significant benefit of the PBL lessons was increasing motivation of students. He especially presented a positive effect on students who had low motivation to learn and often were absent from school. After implementing the PBL lessons, those students visited James' office and showed their products from the PBL lessons. James said that the students were very excited about the lessons. He had a lot of good feedback about the PBL lessons from the students and teachers that indicated the students eagerly engaged in their lessons. James perceived that the PBL lessons are effective to strengthen students' motivation to

learn and engage. Also, teachers were also excited about the lessons because they realized their students' active participation in their lessons. James said,

I have definitely heard the engagement being higher and the excitement and the kids being higher, which is what our teachers want... I've had three or four kids that have already brought me their prototypes of what they're doing, and like, "Oh my gosh, check this out. So, you know how they have those things with your arm in the bathroom? I made one for the foot, so you not only have to use your arm. We can open the doors like that." And they're showing it to me.... They were really really excited about it. I have never seen that with a lot of teachers. (James, Interview #1)

James also explained that the PBL lessons had students find solutions to the local environmental problems and students were able to learn applications of science knowledge to their life problems. He described:

Our goal of the PBL and then our STEM is to act local and to try to find local solutions and we're very lucky to have a campus with lots of lands and a stream and a pond over there. And so, we really have a lot of opportunities to apply what we're learning especially in science to our campus... I liked that their [the teachers] goal was to let them do a lot of discovery in that and let them figure it out and bring in their own ground cover and their own things to implement to reduce the erosion. So, I really like that and then I love the second step. The application of what are we going to do about it? What is the solution to the problem? And that's been one of the big things as we're trying to find our footing. We're trying to find what is our thing. (James, Interview #1)

Furthermore, James understood engineering design is an iterative process like a feedback cycle to find solutions. He perceived that the goal of engineering education in middle school is providing true application what students have learned in school.

In this section, I discussed the administrator's perspectives on integrated STEM lessons and the PBL lessons. Since James understood teachers' difficulties in teaching new instructional strategies, he adopted PBL as an introductory step to transit for integrated STEM education. He considered the school environment, available resources when he planned the PBL lessons. Even though James had challenges for changing inflexible school culture but tried to support teachers by providing diverse professional development opportunities and an open environment. He believed that integrated STEM education can help students develop problem-solving abilities and teamwork skills and motivate them to learn in the context of real-life application.

Summary

In this section, I discussed finding of this study under four sections based on the research questions: benefits of and challenges to implementing integrated STEM lessons, the science teachers' teaching of the project-based learning (PBL) lessons in terms of the engineering design process, the development of the participating experienced teachers' pedagogical content knowledge (PCK) in the context of the participants' teaching of the PBL lessons, and an administrator's perspectives on implementing integrated STEM lessons. The participating teachers understood the term of integrated STEM education in two ways; an approach to teaching that combined domains (i.e., science, technology, engineering, and mathematics) of STEM fields, and an introduction to future careers in the STEM area for their students. The teachers perceived real-world application, developing high-order thinking abilities and teamwork skills, motivation to learn as benefits of implementing the PBL lessons. However, they had

difficulties assessing student achievement, connecting with elementary school's curriculum with limited resources representing space and students' passive learning approach. The participating teachers perceived that their students gradually built products (erosion bottles) and so the students learned along with the engineering design process. The participating teachers' knowledge of instructional strategies for teaching PBL influenced other components of PCK particularly knowledge of orientations to teaching science and knowledge of assessment of student learning. Also, I presented the administrator's perspectives on integrated STEM lessons and the PBL lessons. He perceived that STEM is a useful approach for students to develop problem-solving abilities, teamwork skills, and to provide a learning experience with STEM fields. He tried to change the inflexible school environment and supported teachers to try the new instructional strategies in many ways such as providing opportunities to participate in STEM conferences or professional development programs.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

In this section, I examine the implications of this research study and suggest directions for future research. This research was an examination of a middle school's adoption of PBL as a primary feature of the science curriculum and as an initial step toward implementing integrated STEM curricula. I explored the teachers' teaching of the PBL lessons as a lens to gain insight on implementing integrated STEM lessons.

The overall goal for the science teaching at the middle school where I conducted this research was to move forward in making the science curriculum relevant for today's students and staying in touch with the movement toward STEM that is happening nationally. As such, the sixth-grade science classes were the site of the most extensive implementation of the school's goal and thus the site of this study. At the conclusion of the academic year, the sixth grade middle school science teachers perceived that their students had learned about the engineering design process, developed significant scientific knowledge, and high-order thinking abilities through employing project-based learning (PBL). Even though the teachers did not instruct the students on the engineering design process directly, the students learned it naturally within the whole processes of the PBL unit. As such, their feelings about the students gain in this area match the idea that engineering design is a method of practical application of science knowledge in science classrooms (Brophy et al., 2008). However, this study showed that the engineering design process is useful for learning about scientific reasoning processes and characteristics of

engineering discipline. Furthermore, this study supported that the teachers' pedagogical content knowledge (PCK) was developed through implementing PBL lessons.

Benefits of Integrated STEM Lessons for Student Achievement

Even though the participating teachers presented different perspectives on the definitions of integrated STEM education, they were aware of the needs for integrated lessons, for example, to encourage students to engage in their lessons. In this section, diverse positive aspects of integrated STEM lessons are discussed through exploring the participating teachers' implementation of PBL lessons.

Developing Knowledge of Science and Engineering

In general, engineers try to apply basic principles to particular problems, and scientists attempt to explain the fundamental characteristics of phenomenon by exploring testable traits of nature. The nature of engineering and of science overlap in practice and this overlap was emphasized in the problems that students worked on in the PBL lessons. Consideration of the specific purpose of the design is a pivotal characteristic of engineering and it was in the PBL lessons. In like manner, the scientific study of a concept like erosion was also important to the students' learning. In this study the two disciplines were combined in this project which had a guiding question regarding how to stop erosion around Norton Middle School (NMS, pseudonym).

In this study, the students developed approaches to solving problems that mirrored how engineers design products through the iterative process of engineering design around a learning objective to find solutions to the driving question (how to stop erosion at NMS). The students repeated the processes of brainstorming for creating ideas, developing a model (erosion bottle), testing and optimizing the model. Even though the teachers did not explicitly plan lessons that

taught the integration of engineering design process within their lessons, the process was inherently included in the PBL lessons, thereby allowing the students to learn about the fundamental characteristics of engineers' work. Thus, one major outcome of the PBL lessons was naturally fitted to the engineering component of STEM education.

One implication from this study is that PBL and the engineering design process pursued the highly similar goals for student learning and share similar characteristics. Both pursued helping students to develop problem solving abilities and increase student engagement. This study showed that PBL and engineering design both feature: an investigation with a problem (or a driving question), problem-solving processes, collaboration, use of technology, and creation of final products. In this respect, the engineering design process was easily included in the PBL lessons so that the participating teachers implemented integrated lessons including engineering content. Therefore, the inclusion of the engineering design process in the PBL lessons can be an effective way to implement integrated STEM lessons.

Furthermore, the students in this study learned scientific inquiry skills: questioning, observing, measuring, and analyzing (Lederman et al., 2014) through the PBL lessons. The students had the driving question as a statement of an overall goal for the PBL product; they observed and studied the variables related to erosion phenomena using their erosion bottles, they developed approaches to measuring clarity of filtered water, and they combined their results to find the best solution to stop erosion. Even though the learning objective was not to explain natural phenomena, the students learned scientific reasoning processes through the PBL lessons.

In addition, expansion of the problem that students are working on to a community level can support students in learning how scientists make generalizations as an aspect of the process of science. Chris described how his students developed approaches to apply their particular

models of the erosion bottles to addressing the local or global community erosion problems. This application revealed that the PBL lessons were useful for teaching both characteristics of science and engineering. It is clear from these findings that students developed knowledge of science as well as engineering.

Real-Life Problem-Solving Abilities

As discussed in the literature review, most real-world problems are ill-structured, meaning that they often have multiple goals and multiple possible solutions. The earth science students at NMS developed a variety of approaches to solve ill-structured problems through dealing with unexpected problems. For example, the students in one group found that the clarity of the effluent water was not consistent from one test to the next even though they used the same ground cover materials in the erosion bottle. They discussed this problem with each other and repeated the experiment with an explicit goal to find reasons for the lack of consistency. As shown in this example, the teachers perceived that the students could develop out-of-the-box thinking abilities that could help them cope with unexpected situations through the PBL lessons.

Also, the students developed a self-guided learning approach by conducting the project with minimal direction from the teachers. The engineering design activities were student-centered which promoted students to find unique solutions with their own models. They used the data from their models to address solutions to the driving question. In addition, working in groups provided opportunities for the students to develop teamwork and communication skills including the ability to present ideas and work effectively with others. The students had to persuade and negotiate with each other to decide on their group's prototype among the individual models because each group had to submit one representative model. They used data analysis and evidence to present their ideas, so they learned the reasoning process through the PBL lessons.

PBL provided opportunities for these students to engage in diverse problem-solving situations and the students used these situations to create intuitive versions of engineering design. As a result, these students better understand how science and engineering are relevant to their lives, which in turn helps them understand why they need to learn about science and engineering.

Bridging the Gap between Teachers' Knowledge and Practice

In this study, the gap between teachers' knowledge and their instructional practice was observed during the implementation of the PBL lessons. I analyzed each participating teacher's teaching and their pedagogical content knowledge to investigate the differences.

Influences of the Teachers' Knowledge of Assessment on the Process and the Products of the PBL Lessons

When called on to implement science instruction that was created around a PBL plan, although the participating teachers perceived the importance of implementing the engineering design process, they did not include teaching to explicitly support student learning of this in their lessons. However, gaps between teachers' perspectives and real teaching in the classroom were observed in this study. Teachers' knowledge of assessment was a critical factor that influenced the teachers' teaching and their students' learning outcomes.

Dan's classes showed that the teacher's assessment methods of the integrated lessons influenced the students' learning outcomes. Dan was aware of the importance of learning about the engineering design process, and he perceived it as a benefit of integrated STEM lessons. However, as Dan placed a focus on examining the final results of the student products, this seemed to take the place of students' opportunities to present their solutions to the driving question. Even if the students learned intuitively about the engineering design process through the PBL lessons, students' achievement in terms of the process were not assessed because of the

limited assessment methods that were available to the teachers. For instance, although the students had reasonable reasons (e.g., the use of the limited classroom materials) for their products, they did not have opportunities to explain to them because there was no class discussion at the end of the PBL lessons. Therefore, teachers' assessment content and methods are significant for students to learn about the importance of the process of the project.

In this respect, teachers need to consider their assessment methods when they design the curriculum because assessment definitely influences student learning outcomes (Biggs, 2004). Appropriate assessment methods can bridge teachers' beliefs and their actual teaching. This study showed that the teachers' knowledge of assessment was developed through teaching the PBL lessons. More specifically, Dan recognized the need for various assessment methods such as written-self assessment for improving student learning. Emily also mentioned that formal assessment is necessary for probing student achievement so she can reflect on her teaching methods or content.

The students in Dan's class had little time to reflect on their work and results because their PBL lesson ended after evaluating clarity of filtered water. Students achieve meaningful learning when they reflect on their work including the process to find solutions as well as final results (Hung et al., 2008). Therefore, teachers need to guide their students to reflect on the conducted scientific and engineering practices and student outcomes during the integrated lessons.

On the other hand, Chris emphasized the importance of the final product which was a means of supporting students' meaningful learning and certainly including students' learning about the engineering design process. Chris gave his students opportunities to present their ideas to others by holding a student conference. More specifically, Chris used '*learning technology*'

(Krajcik & Blumenfeld, 2006) for his students to collaborate on the creation of their work and on its presentation to the class by using computer software such as Google Slides and Dropbox. In Chris' PBL lessons his students learned how to organize their ideas and visualize their products and present them using technology. Chris employed *learning technology* as a cognitive tool to support the students to organize their ideas, collaborate with classmates, and present their proposals effectively. In contrast, Emily included technology in her lesson in which the students uploaded pictures on the class website using a cell phone.

Detailed instruction for the evaluation of the final products is necessary as the last step of the PBL lessons. For instance, Dan prepared a frame for the final evaluation of the erosion bottles under the same conditions. He put the erosion bottles on the frame in order to have the same slope when the water poured out. In contrast, Emily and Chris had their students evaluate their erosion bottles, so the students conducted the experiment by manually tilting the bottles at different angles, which resulted in different pouring speeds and different results. Chris evaluated this as the students' mistake: "They poured the water too rapidly into the bottle. So that it flushed all of the soil directly into the cup without giving it a proper amount of time to drain through it." To avoid this kind of mistake, more detailed instruction from the teacher is required.

Assessment Methods of Student Outcomes

In this study, sixth grade science teachers had difficulty assessing their students' achievement of the PBL lessons. For example, even though the participating teachers perceived that the PBL lessons are beneficial for students to develop high-order thinking abilities such as creativity or real problem-solving ability, they did not have assessment methods to measure these domains of students' outcomes. Teachers' actual teaching is difficult to change even though the teachers had professional development aimed toward the new teaching and learning approach

(Guskey, 2002). Guskey (2002) argued that teachers are usually motivated to try to change their traditional teaching strategies after observing improvement of student outcomes. In a similar manner, detailed assessment methods to evaluate student achievement are necessary for teachers to have confidence in teaching integrated STEM lessons. The participating teachers perceived that the learning process along with the PBL lessons is important as well as the final products. Therefore, the development of the assessment methods for the engineering design process is necessary.

Embedded assessment task. If assessment tasks are only at the end of the projects or activities, it is difficult to assess student learning progression or the conducted process that occurred during the lessons. Especially, in the PBL lessons of this study, the lessons were taught for 3 days to 3 weeks and generally integrated STEM lessons include diverse activities and last more than one class period. Therefore, it is difficult for teachers to remember student achievement and to bring it back to assess at the end of the class. In this respect, assessment tasks should be embedded in the activities of integrated STEM education as Biggs (2003) argued that assessment should be considered from the beginning of the lessons. To this end, educators need to consider assessment tasks in parallel with activities at the curriculum designing stage.

Teachers' Knowledge of Instructional Strategies – Project-Based Learning

In this study, the participating teachers' knowledge of instructional strategies was consistent with their orientations to teaching science. The participating teachers showed combined orientations among the nine orientations discussed by Magnusson et al. (1999). Dan showed orientations of the process, activity-driven, guided inquiry, and project-based science. Emily expressed inquiry, didactic and project-based science orientations and Chris showed orientations of project-based science and guided inquiry. As project-based learning was a key

component of the teachers' teaching, the instructional strategy influenced the teachers' orientations to teaching science, specifically in project-based science. As a result, the teachers' knowledge of instructional strategies and knowledge of orientations were developed along with their implementation of the PBL lessons.

Furthermore, the teachers' knowledge of instructional strategies was pivotal in assisting students' learning process and achievement. Dan and Emily exhibited little confidence in teaching PBL lessons because they did not have experience with the PBL lessons. Their teaching focused on conducting the erosion bottle activities rather than finding solutions to the driving question. In contrast, as Chris had the PBL training, he had much knowledge of teaching PBL and implemented his PBL lessons differently from other teachers. For example, Chris and his students walked around the school surroundings to decide target places for their research and the students prepared proposals for stopping the erosion of their specific target place. Chris' students had actual experience to apply their ideas to help the school environment.

On the other hand, the participating teachers' knowledge of students' understanding of science influenced the teachers' instructional strategies and orientations. In particular, Dan described that he had difficulties in adjusting instructional strategies when he taught the students in standard classes. He perceived different characteristics of the student learning based on their developmental levels. Dan described:

Now with gifted kids, I'm more likely to let them do that because there's a good, creative outlet and they would surprise you sometimes with what they can come up with from a creator's standpoint. So, as far as them changing, I don't think I can change the end result because that's the comparison kind of thing that I need to do. I definitely would change, I mentioned this before about feedback. I really

wish I had been able, in some way, along the way let them go to other groups and see what they were doing and balance it out of them. I think I probably would have gotten to higher-level ways of solving the problem from the lower kids if I had done that. So that's something I would definitely change in the future, trying to build that in, and knowing, they're sure they didn't know how long is it going to take. (Dan, Interview #2)

Dan's knowledge of students' understanding was developed along with teaching the PBL lessons and was reflected on changing instructional strategies based on the students' learning progress.

Administrator's Perspectives

James, the assistant principal at Norton Middle School (NMS) was enthusiastic and supportive for encouraging teachers to try new instructional strategies. He pursued employing integrated STEM lessons to provide adequate individual education for students from different backgrounds and different learning development levels. To this end, he started with PBL lessons as a first step to have experience implementing integrated lessons.

In general, experienced teachers are afraid to attempt new curricula or instructional strategies (Abrami et al., 2004; Donnelly & Sadler, 2009). As the NMS had many experienced teachers (90% of the teachers at NMS had teaching experience over 6 years in 2017), James considered this school environment when he made a decision to employ the PBL lessons. He thought that an abrupt transition to integrated STEM education could overwhelm teachers, so he wanted to alleviate the teachers' reluctance by employing PBL. When it comes to school resources and school culture, PBL was the appropriate strategy as a preliminary stage for STEM education.

Challenges

Both the participating teachers and James perceived that the most critical challenge to implementing integrated lessons was lack of experience with the PBL lessons. As they had little practical experience with the PBL lessons, they were not able to prepare for the possible problems that teachers confront. For example, the teachers did not have an assessment plan at the beginning of the PBL lessons: they were not sure what should be assessed and how to assess student achievement through teaching the PBL lessons. The teachers needed to acquire, either create or be provided, formal rubrics and curriculum materials to overcome these obstacles.

While the assistant principal perceived that the middle school had enough resources, the teachers considered limited resources as a challenge to implementing integrated STEM lessons. The teachers needed practical support such as more space for activities as well as human resources. For example, the science teachers had difficulty organizing the PBL lessons due to the limited space and materials. As the teachers had to conduct two activities at the same time, an erosion bottle activity and a stream activity, they felt that they were unable to pay adequate attention to the students' work of the erosion bottle activity of the first class of the PBL lessons. The teachers explained that there was no room to store the stream table so that they had to teach the stream activity with the erosion bottle activity. In addition, the teachers mentioned a need for experts who could help with curriculum designing or evaluation of student outcomes.

Furthermore, as shown in Emily's class, an organization of the class time periods needs to be considered. As the participating teachers' science lessons included many hands-on activities and experiments, one class period was not enough for conducting the activities. If science teachers have more than two consecutive class time periods, students can concentrate on their lessons without interruption. Furthermore, the space issue can be resolved if the activities

finish within the class time periods. Therefore, the school needs to consider flexible class time periods to encourage integrated STEM lessons.

In the opinion of the teachers, the assistant principal focused on possible human resources that the school and county could have provided and overlooked the physical environment that the teachers actually confronted in the classroom. The assistant principal also carried his role by finding resources for strengthening teachers' abilities and confidence in teaching integrated lessons by providing opportunities to have experiences with STEM education such as participating in STEM conferences or professional development programs. This difference of perception could be understood because of their positions (i.e. teachers and administrators). The teachers thought of direct and physical needs because they actually implemented the PBL lessons. In contrast, James tried to support teachers as an administrator, so he considered a broad range of help across the PBL lessons.

In this respect, this study provides both perspectives from in-service teachers and the administrator of the school. This is significant to better understand in-service teachers' actual obstacles that they faced and the administrator's perspectives. Based on the results of this study, administrators can help teachers to overcome barriers when they implement the integrated STEM lessons.

Motivation to Teach

In general, educators emphasized the importance of students' motivation to learn when considering diverse educational issues including implementing integrated STEM education (Bell, 2015; Brophy et al., 2005). However, teachers' motivation to teach is also significant, specifically for implementing new instructional strategies or curricula.

Experienced teachers often have difficulties with changing their traditional teaching strategies and trying to implement innovative curricula because they have confidence in teaching derived from successful experiences with student achievement (Donnelly & Sadler, 2009). However, the participating teachers in this study were not reluctant regarding teaching integrated STEM lessons. These experienced teachers eagerly participated in teaching new curricula. One possible explanation is personal motivation. Teachers' motivation to include concepts of scientific inquiry was critical for their science classroom practices (Crawford, 2007). For example, Chris was enthusiastic to implement the PBL lessons. He participated in the professional development of the PBL training and spent much time preparing the PBL lessons. As shown in a quote below, the teacher's motivation was an influential factor in the teachers' actual teaching, Chris said:

I do like doing the PBL. It makes teaching more exciting for me. I get it's somewhat exciting. And sometimes I get overwhelmed or feel like I might have done everything I need to do to get ready for this. But I just do it anyway. I just go ahead, and my wife will say, "Why you are here? why are you getting home so late?" "Well because I was getting ready for the PBL"... If I don't do something right, I'll just learn from that and just do it and just move on and don't get bummed out or feels frightened or whatever." Less proficient in doing it because you didn't really do it right the first time. So, I enjoy it. (Chris, Interview #2)

Another plausible reason is the school environment. The assistant principal at NMS encouraged teachers to enact integrated STEM lessons and all sixth grade science teachers participated in teaching the new curricula. Therefore, supportive school culture influences teachers' participation in implementing integrated STEM lessons.

Collaboration with Cluster Schools

As the participating teachers pointed out the elementary curriculum as a barrier to teaching science in middle school, understanding the elementary curriculum related to science teaching is important. The Norton Middle School (NMS) had four cluster schools, including elementary and high schools. The middle school teachers at NMS collaborated to teach integrated STEM lessons with elementary and high school teachers.

The cluster high school adopted a project-based learning approach for their STEM curricula. Students chose a topic that they wanted to study and conducted a project over the course of a semester. The teachers provided materials and resources, but they did not directly participate in the students' projects. The assistant principal at the cluster high school said that the students who chose to participate in the STEM curricula showed higher achievement on Georgia's standardized writing tests than the students who were taking courses that were taught using traditional teaching methods. This high school was a model for NMS and shared many experiences with teaching integrated STEM curricula. For example, the cluster high school had specific STEM courses that students could choose. The high school invited teachers from elementary and middle school to share students' achievement and instructional strategies with integrated STEM lessons. Dan mentioned that he visited the high school and learned about the teachers' enactment, difficulties and student learning through employing integrated STEM education. Dan watched student engagement that could encourage him to implement the PBL lessons. Furthermore, Dan recognized that the high school had the same problems such as limited space and classroom management as his school and learned how to solve the problems. Dan obtained some knowledge of the STEM lessons through visiting the high school. He elucidated what he learned from the cluster high school's instruction as follows:

We took a trip to the school and they're already sort of in the STEM school. So, I interviewed some of the kids over there because I was curious about that too. And most of them, I would say, said that they enjoyed it because they got to, they were kind of on their own to problem solve something, not all the time but a lot of time they work. And they like working with other people, they like all that. Some of them said, at times they felt like a little overwhelmed and I understood that too... But for the most part, most of the kids were pretty favorite about it... So, I notice even that they have problems with space like every room is crumpled or something. Now in the days when they're actually pursuing their projects and that was the day when we were kind of there. So, it's a little more hectic on those days than it normally is. Every day is not like that. So, we saw them probably at the most extreme. I could tell that they were having some problems with space. And they were using some rooms that they designated for some things just for that. So, I'm curious about how this will work with the school size, you know if we can pull it out or not. But if not, I'm sure that we will integrate a lot of what they do in STEM (Dan, Interview #1)

Conversely, some teachers from the cluster schools, including elementary and high schools visited Norton Middle School to share the progress with the PBL lessons. The NMS teachers discussed practical issues related to STEM education and obtained comments from experienced teachers with STEM education. This collaboration can support students' learning progress as stated, "Because learning progressions extend over multiple years, they can prompt educators to consider how topics are presented at each grade level so that they build on prior understanding and can support increasingly sophisticated learning" (NRC, 2012, p. 26). In other

words, collaboration with different grades' teachers of the cluster schools can help teachers to connect science curriculum between elementary and middle school.

The Effect of the Professional Development

This study demonstrated the effectiveness of professional development programs in strengthening teachers' motivation to teach. As shown in Chris' interview below, his experience of the PBL training affected his motivation to implement the PBL lessons and he actively prepared the lessons. Chris participated in the professional development for PBL in summer 2016. Even though he also had difficulty teaching the PBL lessons due to his limited teaching experience, he understood the critical characteristics of PBL. Chris explained:

I was kind of introducing PBL to the school and then in sixth grade. I probably did the only PBL lessons. No, I'm not saying the other teachers weren't trying it, but I have specifically that motive in mind and used what I have learned from PBL training from the Sky Institute [pseudonym]. (Chris, Interview #1)

This result is consistent with the finding of the study by Hagg and Megowan (2015). The science teachers who participated in the professional development programs of modeling training showed more confidence in teaching science and engineering practices because they considered the practices that were aligned with the modeling instruction through the training. In this respect, PD programs for PBL lessons and the engineering design process are necessary to increase teachers' motivation to teach integrated STEM lessons. Both experienced in-service teachers and pre-service teachers need learning opportunities for implementing the new instructional strategies.

Implications for Teacher Education

This research focused on experienced in-service science teachers' implementation of integrated STEM lessons through teaching the PBL lessons. As shown in this research, teaching experience with integrated lessons is critical for developing teachers' practical knowledge in teaching integrated lessons. Even though the participating teachers had much teaching experience, they had difficulty implementing the new instructional approach. For instance, the participating teachers mentioned difficulties in organizing the integrated STEM lessons. Even very experienced teachers struggled with classroom management when they implemented the new curricula. Therefore, professional development programs should provide opportunities to have practical experience with STEM curricula. For instance, Chris supported this point as follows:

You have to keep them on task. A lot of kids stay away from their tables and you have to make them work. You're going say, "You really need to go back to your group." So, there's some of that, that I was saying, management is part of one of my weaknesses. I want them to explore. I want them to talk with each other as long as it's a constructive way. I don't want them to be roaming though. They need to stay put and on task and I give some freedom to do that sometimes and to explore. So, I think that's probably my challenge. (Chris, Interview #1)

Also, professional development programs for science teachers should include knowledge of engineering design and its application methods in science classrooms. Understanding engineering design processes is helpful for strengthening teachers' knowledge of engineering that results in higher confidence when teaching engineering.

For pre-service teachers, they need more specific and practical teaching experience. As shown in this study, PBL is an effective strategy to implement integrated STEM lessons, so instructional methodology courses should provide teaching PBL lessons for pre-service teachers rather than giving lectures related to the learning theories.

Moreover, pre-service teachers need to learn about basic knowledge of engineering and engineering design processes. In general, as schools do not have enough engineering education teachers, there is a limitation to helping teachers to teach engineering content in their lessons. Therefore, pre-service teachers need to learn what engineering is and how to integrate engineering content in their lessons to meet the national needs for education.

Implications for the Future Research

This study investigated in-service science teachers' practice in the real classroom when they were in transition to teaching integrated STEM lessons. This research focused on identifying initial difficulties that teachers confronted from the curriculum designing stage. In addition to this study, we need empirical studies about the ongoing difficulties of teachers who have experience with teaching integrated STEM lessons. Even after having experience with teaching the integrated lessons, the teachers might have different or similar challenges. In order to successfully support teachers, we need to understand teachers' unresolved ongoing difficulties in implementing integrated STEM lessons.

This study investigated influences among components of teachers' PCK in the context of implementing the PBL lessons of teaching the erosion topic. Teachers' PCK development is subject-specific, and knowledge of instructional strategies is subject and topic-specific (Magnusson et al., 1999). In this research, knowledge of assessment and knowledge of instructional strategies are critical factors that influenced other components of PCK. These

results are derived from the characteristics of the PBL lessons and the engineering design process. As teachers adopt diverse instructional strategies depending on subjects and topics, more empirical studies are necessary for understanding the development of teachers' PCK within integrated STEM lessons.

Summary

In this section, I discussed the findings of this study and presented implications for teacher education and future research. This study is significant in that it provides support to better understand in-service science teachers' perspectives on integrated STEM education based on their actual teaching. This study is also significant in that it was conducted at a public school that was transitioning from traditional single subject science teaching to integrated STEM lessons. Based on this research, we can move forward to our profession's understanding of the teachers' challenges for implementing integrated STEM lessons as well as the school's environment. Given the significance attached in recent years to STEM education as a next generation of the science curriculum, it is important to obtain insight into effective strategies for supporting teachers and student learning achievement as the curriculum is increasingly shaped as STEM. This study makes an important contribution toward that end.

Limitation of the Study

The participants of this study were three sixth grade earth science teachers and an assistant principal in a public middle school. The participants were selected from 15 volunteers by examining the results of conducted a preliminary survey including their backgrounds, teaching experience and perspectives on the eight NGSS practices. As this study adopted a qualitative research methodology, specifically a multiple case study, perspectives of the participants do not represent all faculty's insights on integrated STEM education. This study investigated individual participant's cases to obtain better understanding of in-service science teachers' perspectives on integrated lessons.

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Appendix A

Interview Questions

Interview #1: Initial interview

Backgrounds and Orientations to Science Teaching

1. Could you tell me about your background in science and science teaching?
2. What do you see as your teaching strengths?
3. What areas do you feel are relatively weak in your teaching?
4. What is science teaching in your mind?
5. How would you describe your teaching style and classroom atmosphere?
6. Could you tell me what you consider as the reasons for learning science in middle school? What are your goals for your students?
7. What do you think makes science difficult for students? How would you help the students overcome their difficulties in learning science? What could make the study of science easier for students?
8. Could you tell me about the classes you are teaching this semester? How are the classes organized?
9. Could you tell me about the students in your (AP, CP, honors or gifted) classes?
10. What do you think are some benefits of STEM education for the students?
11. What do you think are some challenges/drawbacks of STEM education for the students?

Pre-interview: Benefits and challenges of implementing STEM curricula

1. What do you think are some benefits of STEM education? (for the first interview)

2. What do you think are some challenges/drawbacks of STEM education? (for the first interview)
3. What will the students be able to learn through today's lesson?
4. What parts/activities of today's lesson would be difficult for students to learn/conduct?
5. How would you help students who have difficulties with your lesson?

Post-interview

1. How was student learning/performance different with the STEM curriculum compared with traditional science curriculum?
2. What did the students learn through today's lesson?
3. How would you change today's lesson if you taught the same class again?
4. What instructional challenges did you have in teaching the topic today?
5. What abilities did students develop through today's lesson?

Interview #2: Final Interview - Teachers' PCK development

Orientations to teaching science/STEM lessons

1. What are your goals for teaching a class based on the STEM curriculum?
2. What do you expect students to learn from your lessons?

Knowledge of assessment of student learning

1. How do you plan to assess student outcomes?
2. Are your assessment methods in STEM different from those in traditional science classrooms? If so, how is assessment different with the STEM curriculum?
3. How do you recognize if students understand the content/concepts?

4. On what, and how, did you assess your students in the context of today's topic/chapter?
Explain your answer (Adapted Henze, Van Driel, & Verloop, 2008).
5. Did your students reach the learning goals of this chapter? How do you know? Explain your answer (Adapted Henze et al., 2008).

Knowledge of instructional strategies for teaching science/STEM lessons

1. Are your instructional strategies different in STEM from those in traditional science classrooms?
2. How do you describe your teaching style/characteristics? (Or, how do you characterize your teaching?)
3. What are differences in your instructional strategies or activities with the STEM curriculum compared with traditional science classrooms?
4. In what activities, and in what sequence, did your students participate in the context of today's topic/chapter? Please explain your answer (Adapted Henze et al., 2008).
5. What was (were) your role(s) as a teacher, in the context of today's topic/chapter?
Explain your answer.

Knowledge of science/STEM curricula

1. What is STEM education?
2. Are there any changes in science subject matter knowledge that you teach for middle schoolers with the STEM curriculum?
3. How did you organize the lessons for this semester? (Please tell me about the instructional calendar for the STEM classrooms this semester).
4. How does student learning/performance differ with the STEM curriculum?
5. How do you recognize each domain of content within the STEM disciplines?

6. What was (were) your main objective(s) in teaching in context of today's topic/chapter?

Explain your answer (Adapted Henze et al., 2008)

Knowledge of students' understanding in science/STEM

1. How do you recognize students' understanding of the content?
2. What kinds of student misconceptions did you recognize in a lesson/topic?
3. How do you help students correct these misconceptions?
4. What do you expect students to learn from your lesson?
5. Is it more difficult to understand what students know in a STEM class than in a single subject science class?
6. Did your students need any specific previous context of today's topic/chapter? Explain your answer (Adapted Henze et al., 2008).
7. What was successful for your students? Explain your answer (Adapted Henze et al., 2008).
8. What difficulties did you see? Explain your answer (Adapted Henze et al., 2008).

Teacher efficacy

1. What abilities do you want to develop to teach the STEM curriculum successfully?
2. What challenges do you have in implementing the STEM curriculum?
3. How comfortable do you feel teaching integrated STEM curriculum?

Appendix B

Observation Protocol

Evidence		
Orientations to teaching science/STEM curricula	<ul style="list-style-type: none"> • Process • Academic rigor • Didactic • Conceptual change • Activity-driven • Discovery • Project-based science • Inquiry • Guided inquiry 	
Knowledge of assessment of student learning	<ul style="list-style-type: none"> • Types of assessment (diagnostic/formative/summative) • Assessment methods (quiz/questioning/worksheets) 	
Knowledge of instructional strategies for teaching science/STEM curricula	<ul style="list-style-type: none"> • Teacher's role (instructor/facilitator/audience) • Types of activities (lab/hands-on/simulation) • Lecture-based (oral/written/visual) • Differentiation • Peer-teaching • Group work • Online classrooms • Role-playing 	
Knowledge of science/STEM curricula	<ul style="list-style-type: none"> • Vertical curriculum • Horizontal curriculum 	
Knowledge of students' understanding in science/STEM curricula	<ul style="list-style-type: none"> • Misconception • Learning difficulty • Interest • Need • Diversity • Development level 	
Teacher efficacy	<ul style="list-style-type: none"> • Evidence of reluctance/confidence (fear or lack of understanding about integrated lessons/content knowledge) 	

Practices	<ul style="list-style-type: none"> • Asking questions and defining problems • Developing and using models • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations and designing solutions • Engaging in argument from evidence • Obtaining, evaluating, and communicating information 	
Learning and teaching environment	<ul style="list-style-type: none"> • Resources (materials/ class periods) • Teacher collaboration • Student engagement 	

Appendix C

Time Line of the Observation and Interview

Table C1

Data Collection with Chris

Date	Teaching Topic	Data Source	Indication
10/6/2017		Observation Pre/Post interview	Interview #1
10/24/2017		Interview	Initial interview
10/30/2017		Observation Pre/Post interview	Interview #2
10/31/2017		Observation Pre/Post interview	Interview #3
11/1/2017		Observation Pre/Post interview	Interview #4
11/2/2017		Observation Pre/Post interview	Interview #5
11/3/2017		Interview	Final interview
11/8/2017		Observation Pre/Post interview	Interview #6
11/28/2017		Observation Pre/Post interview	Interview #7
2/28/2018		Observation Pre/Post interview	Interview #8

Table C2

Data Collection with Dan

Date	Teaching Topic	Data Source	Indication
10/10/2017		Observation Pre/Post interview	Interview #1
10/23/2017		Observation Pre/Post interview	Interview #2
10/24/2017		Interview	Initial interview
10/31/2017		Observation Pre/Post interview	Interview #3
11/1/2017		Observation Pre/Post interview	Interview #4
11/3/2017		Observation Pre/Post interview	Interview #5
12/7/2017		Interview	Final interview

Table C3

Data Collection with Emily

Date	Teaching Topic	Data Source	Indication
10/12/2017		Observation Pre/Post interview	Interview #1
10/19/2017		Observation Pre/Post interview	Interview #2
10/24/2017		Interview	Initial interview
11/3/2017 2 nd period		Observation Pre/Post interview	Interview #3
11/3/2017 3 rd period		Observation Pre/Post interview	Interview #4
11/7/2017		Observation Pre/Post interview	Interview #5
1/5/2018		Interview	Final interview

Table C4

Data Collection with James

Date	Data Source	Indication
9/15/2017	Interview	Interview #1
12/11/2017	Interview	Interview #2

Table C5

Curriculum Meeting

Date	Data Source	Indication
9/18/2017	Observation	
10/30/2017	Observation	
1/10/2018	Observation	
2/15/2018	Observation	