The Study of Middle School Mathematics and Science Teachers' Practices, Perceptions, and Attitudes Related to Mathematics and Science Integration

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THE STUDY OF MIDDLE SCHOOL MATHEMATICS AND SCIENCE TEACHERS’ PRACTICES, PERCEPTIONS, AND ATTITUDES RELATED TO MATHEMATICS AND SCIENCE INTEGRATION

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ABSTRACT

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The purpose of this qualitative study was to investigate the nature of mathematics and science connections made by sixth and seventh grade mathematics and science teachers in their classrooms. This study also examined the extent to which these connections represented mathematics and science integration and described the teachers’ perceptions of and attitudes about mathematics and science integration. The primary data sources included classroom observations and teacher interviews.

Findings suggested that teacher practices in making mathematics and science connections in the classroom incorporated many of the characteristics of integrated instruction presented in the literature. Teacher attitudes toward integration were found to be generally positive and supportive of integrated instruction. Mathematics teachers shared a common perception of integration being two separate lessons taught together in one lesson. In contrast, science teachers perceived integration to be a seamless blend of the two disciplines. The researcher related these perceptions and attitudes to the teachers’ past experiences with mathematics and science connections and integration, and also to their practices of mathematics and science connections in the study.

Keywords: integration, interdisciplinary curriculum, connections
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DEDICATION

This dissertation is dedicated to my husband, Damian, and our sons, Adam and Mark, with much love.
CHAPTER 1 – INTRODUCTION

Purpose of the Study

The primary objective of this qualitative study is to describe the nature of the mathematics and science connections made by middle school mathematics and science teachers in their classrooms as well as to examine the extent to which these connections represented mathematics and science integration. The theoretical lens used to guide the analysis of data involved the integration approaches proposed by Davison, Miller, and Metheny (1995), mathematics and science integration continuum models developed by Lonning and De Franco (1997) and Huntley (1999), and the five forms of integration identified by Hurley (2001). In addition to examining the teachers’ practices, this study also elucidated teachers’ perceptions and attitudes towards mathematics and science integration to gain a deeper understanding of their actual practices of integration and connections.

The extant literature does not provide a precise definition of mathematics and science integration; consequently, there is a lack of consensus among practitioners and educational researchers about what exactly constitutes integrated instruction (Meyer, Stinson, Harkness, & Stallworth, 2010; Pang & Good, 2000). For instance, Huntley (1999) suggests that integration could involve teaching that is “irrespective of traditional disciplinary boundaries” (p. 60). However, other educators caution against attempts to “blur” the distinction between these disciplines (Lederman and Niess, 1997).

The existing inconsistency in the terminology associated with integration contributes to this debate. In fact, Huntley (1999) suggested that “the plethora of terms
commonly used to refer to integration complicates this definitional problem” (p. 58).

This study addresses this issue by focusing on mathematics and science connections, which, according to Frykholm and Glasson (2005), may be a more “hopeful” and “realistic” approach to promote integration in teacher practices (p. 130).

This study was embedded in a GK-12 program, whose focus on integrated and interdisciplinary mathematics and science education created a set of unique conditions to enable teachers to connect these disciplines in the classroom. As program participants, teachers had an opportunity to work alongside mathematics-science teams of graduate students, who co-taught weekly lessons in mathematics and science in the teachers’ classrooms. The goal of such lessons was to integrate mathematics and science. Although the lessons were co-designed by the graduate students, the teachers acted as educational mentors, providing educational assistance with the planning and implementation of each lesson. Classroom teachers were present during each lesson taught by the graduate students and were responsible for the quality of the classroom management and instruction. In addition, teachers also participated in professional development activities with a focus on integrated and interdisciplinary education.

This research study focused on the teachers’ practices, perceptions, and attitudes of mathematics and science connections and integration, as opposed to those of the graduate students. The researcher sought to learn about the nature of what the teachers connected and how they made the connections and to examine these connections in the context of teachers’ perceptions and attitudes about integration. Teachers’ practices of mathematics and science connections and integration had previously been understudied in
the literature, as were teacher practices in programs similar to the GK-12 program. This study sought to contribute to the literature by filling this gap and presenting insights about integrated instruction.

**Significance of the Study**

The literature presents numerous examples of pedagogical efforts related to the teaching of science and mathematics connections (e.g., Frykholm & Glasson, 2005; Meyer, Stinson, Harkness, & Stallworth, 2010) and integration (e.g., Berlin & White, 2012; Bosse, Lee, Swinson, & Faulconer, 2010; Pang & Good, 2000). However, for students and teachers to experience integrated instruction, activities in mathematics and science connections must become a component of classroom interactions. That is, the mathematics and science teachers need to engage students in activities that reflect the interconnected nature of these disciplines. With continued efforts to study the nature of interdisciplinary connections of mathematics and science that are made or attempted by teachers in the classroom, the body of literature on the pedagogical implications of integrated mathematics and science teaching and learning will continue to expand.

There are many barriers to successful mathematics and science connections in the classroom. Some of the challenges of integration presented in the literature pertain to: a) the development of weak content knowledge in both disciplines (Korsunsky, 2002; Steen, 1991), b) fundamental differences in the knowledge organization of mathematics and science (Isaacs, Wagreich, & Gartzman, 1997; Lederman & Niess, 1997; Steen, 1991), and c) inadequate teacher knowledge of integration models (Roth McDuffie & Morrison, 2008; Steen, 1991). In addition, past efforts to integrate mathematics and science
reflected insufficient understanding of and negative beliefs about integration among teachers (e.g., Lehman, 1994; Lehman & McDonald, 1988), inadequate evidence that an integrated curriculum is more effective than a traditional curriculum (Czerniak, Weber, Sandmann, & Ahern, 1999), a lack of focus on integrated teaching in teacher preparation programs (Mason, 1996; Roebuck & Warden, 1998; Steen, 1991) and university teaching (Meier, Nicol, & Cobbs, 1998), and insufficient time in the curriculum allotted to building connections (Roth McDuffie & Morrison, 2008).

The lack of consensus about the definition of integration in the literature has led many teachers to select activities with identifiable math and science components, but often without a cohesive rationale for why these components were taught together or how best to reveal their interconnectivity in a lesson. The incongruent nature of the existing definitions of integration among the leading scholars in the field of interdisciplinary education is reflected in the literature (Pang & Good, 2000). For instance, Huntley (1999) proposes that teachers who integrate mathematics and science attempt to dissolve the disciplinary boundaries between mathematics and science (p. 60). On the other hand, Lonning and De Franco (1997) describe integration as a balance of mathematics and science, with a focus on the appropriateness of the curricular goals and objectives in both subjects and the instruction being “relevant” and “engaging” for students (p. 212).

The integration of mathematics and science may be particularly beneficial to middle school students. The physical separation of the curriculum, which typically occurs at the middle school level, combined with the lack of communication between science and mathematics teachers, “may lead to fragmentation of concepts in students’ minds”
(Judson & Sawada, 2000, p. 419). This phenomenon may partially be the result of the middle school teachers’ “lack of the content preparation and pedagogical foundation to effectively implement teaching practices recommended by the national science and mathematics education standards in their classrooms” (Basista, Tomlin, Pennington, & Pugh, 2001, p. 615).

For example, Weiss, Banilower, McMahon, and Smith (2001), who studied mathematics and science teachers’ needs and perceptions about their preparedness for teaching, point to the lack of free time during the school day to correlate their teaching practices with those of the other instructors. In science, only 20% of K-4, 27% of 5-8, and 19% of 9-12 teachers reported helping their students to recognize connections between science and other disciplines on a daily basis (p. 80). In mathematics, only 23%, 17%, and 12% of teachers in the respective categories reported helping students connect math with other disciplines.

The literature suggests that teaching is embedded in many contexts, including the teachers’ own classrooms, their interactions with colleagues, professional development opportunities, and graduate programs (Barnett & Hodson, 2001; Bransford, Brown, & Cocking, 1999). By supporting teachers’ collaborations with their colleagues and visiting scientists in the context of their own classrooms, this program encouraged integrated, interdisciplinary teaching. Thus, with its focus on mathematics and science connections in the weekly collaboration of mathematics and science teachers and graduate students in the middle school classroom and professional development activities, this program was selected as an appropriate setting for conducting a qualitative study of middle school
teachers’ practices, perceptions, and attitudes related to mathematics and science
connections and integration.

**Research Questions**

This study addressed the following questions:

1a.) What is the nature of mathematics and science connections made by middle
school mathematics and science teachers in the GK-12 program?

1b.) What is the extent to which these connections represent mathematics and science
integration?

2.) What are the GK-12 middle school mathematics and science teachers’ perceptions
and attitudes about mathematics and science integration?

**Definitions of Terms**

Little agreement exists in the literature with respect to the definition of integration
(e.g., Czerniak, Weber, Sandmann, & Ahern, 1999; Meyer, Stinson, Harkness, &
Stallworth, 2010). Nevertheless, based on the research literature, the researcher utilized
the following descriptions of *integration* of mathematics and science, *interdisciplinary*
curriculum, and *connections*:

1. *Integration* of mathematics and science:
   a. *Total Integration*: Mathematics and science taught in intended equality
   b. *Balanced Mathematics and Science*: There is a balance of equally
      appropriate mathematics and science concepts or activities in a lesson or
      activity. In this context, “equally appropriate” refers to mathematics and
science concepts that meet the curricular goals and objectives in mathematics and science for the given grade level (Lonning & De Franco, 1997, p. 213).

c. **Integrated curriculum:** An explicit assimilation of mathematics and science concepts with approximately equal attention to each discipline, with the boundaries between disciplines remaining indistinguishable throughout instruction; the disciplines of mathematics and science interact and support each other (Huntley, 1998, 1999).

2. **Interdisciplinary curriculum:**

   The focus of instruction is on one discipline, with the other discipline supporting the teaching and learning in the first discipline. The connections between mathematics and science are made implicit in the lesson, in contrast to an integrated curriculum, which makes these connections explicit (Huntley, 1998, pp. 320-321).

3. **Connections:**

   a. **As a process:** As proposed by the National Council of Teachers of Mathematics (2000), connecting mathematics and science entails seeing and experiencing the interplay between these subjects as well as recognizing and applying mathematics in science.

   b. **As a notion:** Connections are situated authentically in science and mathematics practices and the common experiences of learners (Frykholm & Glasson, 2005, p. 130).
CHAPTER 2 – LITERATURE REVIEW

The fast-paced scientific and technological advances of the 20th and 21st centuries have made high-quality mathematics and science teaching and learning imperative to the academic and professional success of today’s students. The 2011 assessment framework of the Trends in International Mathematics and Science Study (Mullis, Martin, Ruddock, O’Sullivan, and Preuschoff, 2009) includes the following statement that highlights the importance of science learning for all students:

In today’s world, some understanding of science is imperative if citizens are to make informed decisions about themselves and the world in which they live. Every day they are faced with a barrage of information, and sifting fact from fiction is possible only if they have the tools to accomplish this. It is important, therefore, to make certain that students leaving high school are equipped with a fundamental understanding of science such that the decisions they make are informed decisions. (p. 49)

Mullis et al. (2009) make a similar argument about mathematics education:

Students should be educated to recognize mathematics as an immense achievement of humanity, and to appreciate its nature. Nevertheless, learning mathematics for its own sake is probably not the most compelling reason for universal inclusion of mathematics in school curricula. Prime reasons for having mathematics as a fundamental part of schooling include the increasing awareness that effectiveness as a citizen and success in a workplace are greatly enhanced by knowing and, more important, being able to use mathematics. (p. 19)
As the education community continues its efforts to enhance the teaching and learning of science and mathematics, the instructional practices that focus on the integration of these disciplines in the classroom present teachers with opportunities to provide students with meaningful learning experiences in mathematics and science. The study of these practices is important to the future of mathematics and science teaching and learning.

**Teacher Knowledge of Science and Mathematics**

The results of national and international studies on the quality of science and mathematics education in the United States suggest that the academic achievement of students (e.g., Fleischman, Hopstock, Pelczar, & Shelley, 2010; Gonzales et al., 2008; National Center for Education Statistics, 2011, 2012) and the quality of teaching (Roth & Givvin, 2008) need to be improved in both disciplines. However, the improvement of student learning in mathematics and science cannot be achieved without the pedagogical and academic expertise of well-qualified educators, who can provide students with knowledge-rich learning environments.

Furner and Kumar (2005) suggest that the preparation of “successful individuals of tomorrow” requires effective teaching in mathematics and science (p. 185). The quality of mathematics and science education depends upon the teachers’ classroom practices, and, thus, “teachers should have the knowledge of how students learn science and mathematics and how best to teach” (p. 185). Roth and Givvin (2008) support this view and emphasize that mathematics and science educators need a strong content knowledge and pedagogical content knowledge base for effective teaching to enable
students to learn in contexts that stimulate the formulation of meaningful understandings and connections in each subject.

*The Report of the 2000 National Survey of Science and Mathematics Education* (Weiss, Banilower, McMahon, & Smith, 2001), which provided information about and identified trends in teacher background, experience, curriculum, instruction, and instructional resources from a total of 5,767 science and mathematics teachers in the United States, found evidence of inadequate teacher knowledge in science and mathematics content and instruction. This report found that about 67% of K-4, 42% of 5-8, and 37% of 9-12 science teachers were “not at all familiar” with the science standards proposed by the National Research Council (1996), and about 38% of K-4, 27% of 5-8, and 15% of 9-12 mathematics teachers made similar declarations about their familiarity with the mathematics standards proposed by the National Council of Teachers of Mathematics (2000). These results cast doubt on teachers’ awareness of trends and recommendations in education.

Furthermore, the report found that 20% of K-4, 39% of 5-8, and 64% of 9-12 science teachers and 40%, 57%, and 69% of mathematics teachers, in corresponding grade levels, considered themselves to be “master” teachers of their subject area (p. 41). Nevertheless, deeper analyses of the teachers’ educational backgrounds revealed that many K-8 science and mathematics teachers did not have a strong content preparation in their respective subject areas (p. 45). In fact, a majority of the surveyed K-8 teachers majored in education rather than mathematics or science. As many as 46% of all middle
school mathematics teachers reported feeling “not well qualified” to teach functions, and only 57% felt “very well qualified” to teach algebra.

The literature suggests that efforts aimed at strengthening mathematics and science teachers’ knowledge of content and pedagogy are important to the future of mathematics and science education. According to Roth and Givvin (2005), school principals can support mathematics and science teachers by providing professional development opportunities that “strengthen teachers’ content knowledge and pedagogical knowledge in the context of studying instructional practice (their own and others’) over time” (p. 26). If these opportunities involved activities that focused on the connections of mathematics and science, then these efforts could lead to more successful lessons in both disciplines, and, ultimately, result in effective integrated and interdisciplinary instruction.

**Mathematics and Science Learning in Context**

The educational merits of teaching specific topics by clearly defining their context within the broader structure of a field of knowledge have been known to educators for quite some time (e.g., Bruner, 1960; Frykholm & Glasson, 2005). This contextually-based approach to teaching and learning has been the focus of studies in situated learning theory, which is based on the idea that much of what is learned is specific to the situation, or context, in which it is learned (Anderson, Reder, & Simon, 1996). More specifically, since both teaching and learning occur in social contexts, situated knowledge results from learning experiences in activity, content, and cultural contexts embedded in authentic, relevant problem situations (Brown, Collins, & Duguid, 1989, p. 32). Hence, for two strongly interconnected school disciplines such as mathematics and science, the
acquisition of knowledge in one discipline, when it is situated in the context of the other discipline, will have important implications for improved student learning gains in both contexts.

In a report on how students learn, targeted towards teachers, the National Research Council (2005) highlighted the impact of instruction in science and mathematics contexts on student learning as follows: “Competent performance is built on neither factual nor conceptual understanding alone; the concepts take on meaning in the knowledge-rich contexts in which they are applied” (p. 6). Furthermore, this report emphasized the need for students to connect what is being learned with their existing knowledge schemas, or categories of knowledge, to achieve effective and efficient learning outcomes. Thus, as suggested by Frykholm and Glasson (2005), meaningful connections of the newly acquired knowledge with the existing understanding of the subject matter can be expected when learning occurs in contexts that are situated in integrated mathematics and science settings. By calling integrated practices “necessarily situative” (p. 129), these scholars suggest that learning opportunities situated in contexts that embed mathematics and science connections could have a positive impact on student learning in both disciplines.

To enable students to learn in meaningful, knowledge-rich contexts in science and mathematics (including contexts in which mathematics and science are integrated), mathematics and science teachers need to recognize and respond to the contextually-based learning outcomes of every classroom experience, and determine when narrower or broader contexts are required and when they become optimal for effective and efficient
learning (Anderson, Reder, & Simon, 1996). For this purpose, teachers need to function within these various learning contexts to maximize their students’ learning gains as well as their own. What this means for mathematics and science integration is that teachers need to experience and reflect upon integrated instruction in their classrooms in order to learn about the role and impact of integration on teaching and learning of these subjects.

As adult learners, teachers can gain new knowledge for teaching in a variety of contexts, including interactions and collaborations with other teachers and teacher educators in schools, teacher enhancement projects, professional development programs, coaching, youth-related work, or graduate programs (Barnett & Hodson, 2001; Bransford, Brown, & Cocking, 1999). Teachers can also learn by reflecting on their own and other teachers’ instructional practices. Thus, it is important to continue to study what teachers do in their classrooms, as the context of a classroom can resonate with their perceived needs and stimulate the need for a change in the daily teaching strategies.

Integration in Mathematics and Science Reforms

In recent decades, the integration of mathematics and science has gained approbation from many academic scholars (e.g., Berlin, 2012; Bosse, Lee, Swinson, & Faulconer, 2010; Czerniak, Weber, Sandmann, & Ahern, 1999; Furner & Kumar, 2007; Isaacs, Wagerich, & Gartzman, 1997; Karsai & Kampus, 2010; Lehman, 1994); however, the integrated teaching and learning of mathematics and science is not new to the education community. In fact, a century ago, John Dewey compared and contrasted two different approaches to teaching: the progressive approach of experience-based, student-centered learning contexts governed by student agency and characterized by scientific
inquiry, and the traditional approach of rote learning, symbol interpretation, and teacher-directed instruction, guiding students into passive, submissive roles (Dewey, 1902).

Strongly opposed to teacher-made curricular divisions and fractionalization, Dewey perceived the connections of content knowledge and practical commonsense as desirable outcomes of productive learning and strongly supported inquiry-based teaching and learning (p. 188). Decades later, the recommendations of American Association for the Advancement of Science (1989) solidified his vision of inquiry-based learning by calling for more coherent, integrated, and effective curricula through collaborative efforts involving teachers, school administrators, and education policymakers (pp. 211-212).

In both mathematics and science, rich learning environments that allow students to make connections across the curriculum, to develop critical thinking and problem solving skills when engaged in inquiry-based learning, have been recognized by national science and mathematics standards as instruments of effective teaching (Moscovici & Newton, 2006; NCTM, 2000; NRC, 1996, 2000; Rutherford & Ahlgren, 1990). In their historical analysis of scholarly documents focused on the integration of mathematics and science, Berlin and Lee (2005) emphasize the role that integrated teaching has played in the development of both national and state reform efforts and state frameworks since 1901 (p. 23). As the key components of the school curriculum, mathematics and science have solidified their position as academic pillars of a well-rounded education. Their connected nature amplifies the meaningfulness and relevance of school learning.

In searching for connections between science and mathematics learning, Bosse, Lee, Swinson, and Faulconer (2010) compared the five process standards of the
Principles and Standards for School Mathematics (NCTM, 2000) with the learning cycle or the 5 E’s (Engagement, Exploration, Explanation, Elaboration or Extension, and Evaluation) from the National Science Education Standards (NRC, 1996) and the Inquiry and the National Science Educations Standards (NRC, 2000). The authors found the process standards in mathematics and the process standards in science to be significantly alike (p. 274). Zilliox & Schultz (2006) supported this conclusion by stating:

Skills that are typically associated with the domain of science, such as hypothesizing and observing, are also tools for understanding and generating mathematical ideas. Tools and processes of mathematics, such as quantification, symbolic representation, and modeling, can support a stronger understanding of science concepts. (p. 355)

The connections of these process standards helped to emphasize the role that integration could play in mathematics and science classrooms.

Mathematics Reforms

The Principles and Standards for School Mathematics (NCTM, 2000), one of the most prominent documents in the recent reform efforts in mathematics teaching and learning, advocated that instructional programs from kindergarten to grade 12 (K-12) should enable students to recognize, understand, and implement connections among mathematical ideas, and recognize and apply mathematics in contexts outside of mathematics, and in particular, to science:

The opportunity for students to experience mathematics in a context is important. Mathematics is used in science, the social sciences, medicine, and commerce.
The link between mathematics and science is not only through content but also through process. The processes and content of science can inspire an approach to solving problems that applies to the study of mathematics. (p. 66)

By proposing that problem solving, reasoning and proof, communication, connections, and representation as five process standards in mathematics teaching and learning, NCTM (2000) validates the interconnectedness of mathematics and science processes. The *Connections* Standard advocates teaching mathematical connections in contexts that relate mathematics to other subjects to allow students to learn about the utility of mathematics (p. 4).

Most recently, the *Common Core State Standards for Mathematics* (Common Core State Standards Initiative, 2010) proposed a new set of curricular and instructional guidelines for mathematical content and practice and reinforced the existing need in mathematics classrooms for learning to be situated in realistic contexts (p. 7). Inherent in the new standards are specific examples of scientific contexts for mathematics learning and instruction, including contexts that involve such topics as bacterial growth and the flight paths of airplanes. In addition, the mathematical practices of looking for and expressing regularity in repeated reasoning, maintaining oversight of mathematical processes, modeling with mathematics, using appropriate tools strategically, or attending to details (p. 8), among others, coincide with the objectives of the scientific method.

The *Principles and Standards for School Mathematics* (NCTM, 2000) and the *Common Core State Standards for Mathematics* (CCSSI, 2010) provide teachers and educators with the initiative necessary to integrate mathematics and science education.
Both documents emphasize the need to move away from the development of a solely procedural knowledge base in the direction of conceptual learning and understanding. When connecting content and/or processes in mathematics and science, mathematics teachers can reach this goal by engaging students in activities that are meaningful to both disciplines.

**Science Reforms**

In *Science for All Americans*, the American Association for the Advancement of Science (1990) supported the relationship between mathematics and other fields of basic and applied science, citing the following:

1) Science and mathematics are part of the same endeavor, since both are trying to discover general patterns and relationships. Science provides mathematics with problems to investigate, and mathematics provides science with tools to analyze data (p. 17).

2) Mathematics is the chief language, the grammar, of science.

3) Mathematics and science have many features in common, including a belief in understandable order and interplay of imagination and rigorous logic (p. 18).

A similar position is reflected in the *Benchmarks for Science Literacy* (AAAS, 1993), which recognized the uniqueness of mathematics and science connections, while still supporting the relationship between these disciplines. This document stated:

It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human
enterprises has a character and history of its own, each is dependent on and
reinforces the others. (p. 3)

Further, the National Science Education Standards proposed by the National Research
Council in 1996 reasserted the importance of the integration of science and mathematics
education in the following statement, “The science program should be coordinated with
the mathematics program to enhance student use and understanding of mathematics in the
study of science and to improve student understanding of mathematics” (p. 214).

Most recently, connections between mathematics and science were addressed in
the science content and practice standards of the Next Generation Science Standards: For
States, By States proposed by the Next Generation Science Standards Lead States (2013).
The connections to the Common Core State Standards for Mathematics (CCSSI, 2010)
were described in Appendix L of the Next Generation Science Standards. By exposing
these interdisciplinary connections, teachers can fulfill recommendations of the scientific
community for more meaningful learning experiences in science and mathematics.

**Defining Integration**

Despite the years of extensive scholarly discourse about the precise nature of
mathematics and science integration, the academic community has yet to agree upon a
precise definition of integration (e.g., Berlin & White, 1992; Davison, Miller, &
Metheny, 1995; Huntley, 1999; Pang & Good, 2000; Stinson, Harkness, Meyer, &
Stallworth, 2009). Berlin and Lee (2005) found a “plethora of terms” with varying
meanings being used to define integration, including: connections, cooperation,
coordinated, correlated, cross-disciplinary, fused, interactions, interdependent,
interdisciplinary, interrelated, linked, multidisciplinary, united, or transdisciplinary (p. 18). Berlin and Lee also suggested that these terms represented various degrees of integration, including: mathematics taught as a prerequisite tool for science; mathematics applied to science problems; science phenomena translated into mathematical terms, and science and mathematics taught in concert in a real world problem-solving context (p. 18).

Lederman and Niess (1997) compared science and mathematics integration to a chemical compound and a chemical mixture. A chemical compound, similar to a smooth tomato soup with the ingredients combined into one product, is a metaphoric model of full integration, in which mathematics and science content and processes intertwine seamlessly to form new knowledge domains in both disciplines. However, a chemical mixture, like a chunky chicken noodle soup with each ingredient being easily identifiable, maintains the integrity of its parts, resembling instruction characterized by clearly defined disciplinary boundaries of mathematics and science (p. 57).

Due to the inconsistency in the existing definitions of integration, the quality and form of integrated lessons is highly dependent upon the teachers’ individual perspectives on integration. Teachers might implement integrated lessons in modern classrooms in a variety of ways--from totally separate to fully integrated (Lewis, Alacaci, O’Brien, & Jiang, 2002, p. 173). Thus, whereas the integration of mathematics and science may be viewed by some teachers as a seamless merger of the two disciplines (e.g., Berlin & White, 1992; Huntley, 1998, 1999) - what Roebuck and Warden (1998) refer to as ‘true integration’ and Huntley (1998) calls ‘full integration’ -- others may choose to refrain
from implementing full integration and attempt to maintain the traditional disciplinary boundaries between these disciplines.

In the context of these divergent approaches to integration, teachers who claim to integrate mathematics and science in their classrooms might be referring to diametrically opposed teaching objectives, methods, outcomes, and assessments, than their colleagues from other schools or classrooms. Thus, unless there is a less ambiguous understanding of what constitutes integration, any future efforts to improve or evaluate the quality and development of integrated instruction remain difficult.

**Integrated vs. Interdisciplinary Teaching**

The literature presents integration as related to an interdisciplinary approach to teaching and learning. Jacobs (1989) defined interdisciplinary as “a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience” (p. 8), and this definition reflected characteristics common to integration. In addition, Berlin and Lee (2005) suggested that the term interdisciplinary was used in the literature to refer to “integration” (p. 18). The connections between these terms were also supported by Barton and Smith (2000) who defined integrated instruction as “addressing content from several subjects simultaneously” (p. 54).

However, in addition to relating the terms interdisciplinary and integrated, the literature also includes evidence of differences between integrated and interdisciplinary instruction (Huntley, 1998, 1999; Lederman & Niess, 1997). For instance, Lonning, De Franco, and Weinland (1998) suggest that the process of integration can reveal the nature
of the relationship between two or more disciplines, including mathematics and science, presented in an interdisciplinary unit (p. 313). Barton and Smith (2005) also propose that *integrated* instruction could remove the artificial divisions among subjects and enable students to see the connections within content areas (p. 54). This suggests that the extent of integration in interdisciplinary lessons involving mathematics and science could vary, and result in learning experiences that expose relationships between these disciplines.

In the study involving the role of mathematics and science in integrated and interdisciplinary lessons, Huntley (1998) differentiates between *intradisciplinary*, *interdisciplinary*, and *integrated* curricula. Specifically, Huntley suggests that an intradisciplinary curriculum focuses on a single discipline, and an interdisciplinary curriculum uses one discipline to teach and learn another. However, an integrated curriculum implies a strictly “explicit assimilation of concepts from more than one discipline by teacher(s) during instruction” and is “typified by approximately equal attention to two (or more) disciplines” (p. 58). In integrated instruction, teachers attempt to infuse one discipline into the teaching and learning of another discipline to attain mutually beneficial learning outcomes in both disciplines (p. 59). Thus, whereas integrated instruction focuses on the learning goals and objectives in both mathematics and science, this requirement is not as ubiquitous in interdisciplinary teaching.

Like Huntley (1998, 1999), Frykholm and Glasson (2005), Lederman and Niess (1997), and Lonning, De Franco, and Weinland (1998) also propose differences between integrated and interdisciplinary instruction. For instance, Frykholm and Glasson (2005) view *interdisciplinary* teaching as preserving “the integrity of disciplinary boundaries”
through the “exploration of common contexts that promote learning of both science and mathematics,” and integrated teaching as a seamless blend of these disciplines “so that it is difficult to tell when the mathematics stops and the science begins” (p. 130). These views of integrated and interdisciplinary instruction not only expose characteristics that relate these instructional approaches but also highlight the differences between them.

Frykholm and Glasson (2005) emphasize the pedagogical limitations that exist in the process of mastering the content knowledge and the pedagogical content knowledge necessary to successfully integrate mathematics and science, and call such expectations “unrealistic” (p. 130). Instead, these educators argue in favor of mathematics and science connections as a required characteristic of integrated instruction. In connected teaching, teachers build lessons based upon the connections between mathematics and science and create learning contexts for their students that expose mutually complementary elements of these disciplines.

Models of Integration

The apparent lack of consensus about the definition of integration continues to complicate the theoretical, pedagogical, and curricular reform efforts of mathematics and science education communities (Berlin & White, 1994, 2005, 2012; Frykholm & Glasson, 2005; Lederman & Niess, 1998). Berlin and White (1994) suggest, “If educators are to explore and harness the potential of the integration of science and mathematics education, a common language must first be established” (p. 2). In the absence of shared definitions that clarify practice, teachers’ views and perceptions of
integrated and interdisciplinary units vary greatly, affecting the nature of classroom instruction (Jacobs, 1989, p. 6).

The literature contains multiple models of integration, including a continuum model used to represent the range of degrees of integration. For instance, Jacobs (1989) proposed a Continuum of Options for Content Design, which included Interdisciplinary Units/Courses, Integrated-Day Model, and Complete Program as the strongest design options for an integrated curriculum (pp. 16-18). A continuum model was also utilized by Fogarty (1991) who proposed ten curriculum integration models to help “students make valuable connections while learning” (p. 61). These models were grouped into the following categories: within single disciplines (the fragmented, connected, and nested models), across disciplines (the sequenced, shared, webbed, threaded, and integrated models), within learners (the immersed model), and across networks of learners (the networked model). Figure 1 presents Fogarty’s models organized along a continuum.

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Figure 1. Ten curriculum integration models of Fogarty (1991). These models form a continuum of curriculum integration. The continuum begins with models within single disciplines (starting with the fragmented model, followed by the connected and nested models) and ends with models that integrate within learners and finally across networks of learners (p. 61).

The fragmented model represents the traditional design, characterized by separate and distinct disciplines. In this model, teachers in the same discipline are expected to
collaborate with each other in order to “sift out curricular priorities within their own content area” (p. 61). The connected model relates topics within a single discipline by exposing relationships and connections between ideas, topics, skills, or concepts within it. The nested model represents a multi-objective approach to lessons, which connected multiple elements or layers of a single topic or theme. On the continuum, these models are the opposite of the immersed model, which focuses on the integration of multiple disciplines within a learner with little or no outside intervention, and the networked model, requiring the learner to reach out to resources connected to his/her interests.

In the middle of the continuum are five across disciplines integration models, with the webbed model being at the center of the continuum. The integration model requires teachers to find interdisciplinary topics with an overlapping theme or concept. The remaining four models view integration as the sequencing of curricular concepts in more than one discipline taught separately (the sequenced model), shared planning or teaching in two disciplines (the shared model), teaching several disciplines under a common conceptual theme (the webbed model), and organizing the curriculum around thinking skills or social skills (the threaded curriculum).

Similarly to Fogarty (1991), who proposed ten models of curriculum integration, Vars (1991) addressed the need for teachers to “lessen some of the fragmentation” in “over-departmentalized school curriculum” (p. 14) and introduced three forms of integrated curriculum: the total stuff approach (with an all-school theme studied for a period of time), the interdisciplinary team approach (with teachers of different subjects correlating some of their teachings), and the block time and self-contained classes
approach (with one teacher providing instruction in several subjects). Like Fogarty (1991) and Jacobs (1989), Vars emphasized the need for student-centered integrative curricula, in which teachers and students collaborate to develop and explore new units of study (p. 14). This educator focused on the process of curriculum development, in addition to the structure of the integrated curriculum.

Davison, Miller, and Metheny (1995) propose five approaches to curriculum integration: discipline specific, content, process, methodological, and thematic. These approaches reflect the roles that mathematics and science can play in the lesson. For example, the discipline specific approach involves two or more different branches of mathematics or science, and the basic concepts, skills, and procedures in one discipline are taught separately from those in the other discipline. The content-specific approach requires teachers to weave one mathematics objective and one science objective together in a lesson. The process approach focuses on real-life activities in the classroom; that is, students experience the processes of science: formulate questions and answers, collect and interpret data, while performing mathematical operations. The methodological approach implements strategies of inquiry and discovery, shared by mathematics and science. This model is an alternative to the traditional stimulus-response learning model (p. 229). The thematic approach involves a common theme, which then becomes the medium for discipline interactions (p. 229).

Based on the work of Davison, Miller, and Metheny (1995), Roebuck and Warden (1998), and Czerniak et al. (1999), Meyer, Stinson, Harkness, and Stallworth (2010) have recently proposed seven integration models: process, pedagogical, thematic, discipline-
specific, concept-specific, project-based, and synergistic. For instance, the concept-specific, thematic, and discipline-specific models reflect the integration criteria proposed by Davison et al. (1995). In addition, with its focus on the creation of science contexts to practice math skills, the pedagogical integration model appears related but not identical to content-specific and methodological integration approaches of Davison et al. (1995). Finally, the synergistic and project-based models involve conditions characteristic of a true integration (Huntley, 1999), or math and science in concert (Czerniak et al., 1999), where students learn mathematics and science in contexts which dissolve the traditional disciplinary boundaries between these two disciplines.

**The continuum models.** In one of the first academic attempts to define integration, the 1967 Cambridge Conference listed five categories of mathematics and science interactions: 1) mathematics for the sake of mathematics, 2) mathematics for the sake of science, 3) mathematics and science, 4) science for the sake of mathematics, and 5) science for the sake of science (Education Development Center, 1969). Since then, these categories have been transformed into a continuum model that shows the more precise extent of interaction between mathematics and science (e.g., Brown & Wall, 1976; Huntley, 1998, 1999). Brown and Wall (1976) first described a five-point continuum, from mathematics for the sake of mathematics (first point) to science for the sake of science (fifth and final point). Three remaining categories were placed between points one and five, with mathematics and science in concert placed at the center of the continuum.
Analogous to the academic discourse on integration, Lonning and De Franco (1997) proposed the *Continuum Model of Integration*, with five types of integration: *independent mathematics* (a purely mathematical context, no science), *mathematics focus* (science supporting mathematics), *balanced mathematics and science* (both subjects receiving equal support), *science focus* (mathematics supporting science), and *independent science* (a purely scientific context, no mathematics) (p. 313). The ends of the continuum contain activities involving only one discipline. Activities meeting the curricular objectives of both science and mathematics are placed at the center of the continuum, e.g. *balanced mathematics and science* (p. 313).

Similarly to Lonning and De Franco (1997), Huntley (1998, 1999) proposed the *Mathematics/Science Continuum* model. This model placed integration of mathematics and science at the center of the continuum (p. 321). However, despite the similarities between Huntley’s *Mathematics/Science Continuum* model and Lonning and De Franco’s *Continuum Model of Integration*, Huntley (1998) pointed out the “crucial differences” at the center of the two continua (p. 322). The alleged differences lie in the structure of the middle section of the models. For example, Huntley’s model calls for a synergistic union of the two disciplines, or full integration, in which students learn “more than just the mathematics and science content” contained in each lesson (Huntley, 1998, p. 322). In contrast, the Lonning and De Franco model’s *balanced* focus in the middle of the continuum requires the equal treatment of both disciplines, without delineating the boundaries between them.
The focus on the equality of focus on the teaching and learning of mathematics and science in integrated lessons is also reflected in research by Hurley (2001). Based on the qualitative evidence from a meta-analysis of 31 interdisciplinary studies of science and mathematics achievement in integrated settings, this educator identified multiple forms of integration in the literature, including: *sequenced* (both disciplines planned and taught sequentially, with one preceding the other), *parallel* (both disciplines planned and taught simultaneously through parallel concepts), *partial* (both disciplines taught partially together and partially as separate disciplines in the same classes), *enhanced* (one discipline dominates instruction, with the other being apparent throughout the instruction), and *total* (both disciplines being taught together in intended equality).

![Integration Types Diagram](image)

*Figure 2.* The Mathematics/Science Continuum model of Huntley (1999) and the integration types of Hurley (2001). These educators highlight the teaching and learning of mathematics and science in intended equality in integrated lessons.

The integration types identified by Hurley (2001) involve the arrangement of the mathematics and science topics in integrated lessons; however, as shown in Figure 2, the extent of integration present along the Mathematics/Science Continuum model (Huntley, 1999) is also reflected in those integration types. In particular, the definitions used to describe *Enhanced* and *Total* integration resemble descriptions of lessons referred to by...
Huntley as *Mathematics with Science* (or *Science with Mathematics*) and *Mathematics and Science*, respectively. Both educators emphasize the teaching of mathematics and science in intended equality in integrated lessons.

**BWISM model for integration of mathematics and science.** Based on the results of the National Science Foundation (NSF) and School Science and Mathematics Association (SSMA) Wingspread Conference in 1991, Berlin & White (1994) stated that “the integration of science and mathematics cannot be simply defined” (p. 2). These educators proposed the *Berlin-White Integrated Science and Mathematics* (BWISM) Model as “a template to characterize current resources, guide in the development of new materials, and provide a common language to advance the research base related to integrated science and mathematics teaching” (p. 2). The BWISM model identified the following six aspects of science and mathematics integration:

1. *Ways of Learning:* students become actively engaged in their learning of science and mathematics, participate in exploratory learning processes, and discuss their findings in larger social settings
2. *Ways of Knowing:* students move back and forth between inductive and deductive thinking and reasoning
3. *Process and Thinking Skills:* students collect and use information through investigation, exploration, experimentation, and problem solving and engage in scientific inquiry and mathematical problem solving
4. **Content Knowledge:** students examine concepts, principles, and theories of science and mathematics that are unique to each discipline as well as those which overlap these disciplines

5. **Attitudes and Perceptions:** students engage in activities which encourage, support, and nurture their confidence to achieve a higher level of mathematics and science literacy

6. **Teaching strategies:** students are engaged in collaborative activities which involve alternate forms of assessment, inquiry-based/problem-solving learning, and are given opportunities to communicate their ideas with each other, to use laboratory instruments and technology

Presently, the BWISM model remains as one of the most recognizable and intuitive models available to academic scholars attempting to study or to implement integrated mathematics and science teaching and learning.

**Impact of Integration on Learning**

The literature presents some evidence to support the need for integrated mathematics and science learning contexts (e.g., Lehman, 1994; McBride & Silverman, 1991; Pang & Good, 2000). Specifically, some scholars suggest that curricular integration can lead to improved academic achievement (e.g., Berlin & White, 1994; Friend, 1985); more efficient implementation of process standards (e.g., Bosse, Lee, Swinson, & Faulconer, 2010); more efficient sequencing of curricular topics (Isaacs et al., 1997); increased motivation and engagement in learning (e.g., Berlin and White, 1994; Isaacs, Wagreich, & Gartzman, 1997), and enhanced opportunities for teacher
learning about the interconnected contexts of mathematics and science (e.g. Douville, Pugalee, & Wallace, 2003). In addition, Furner and Kumar (2007) suggest that student-centered, inquiry-based learning contexts enable students to make interdisciplinary connections through real-world applications of mathematics and science (p. 185).

Hurley (2001) studied the impact of mathematics and science integration on student achievement. Hurley concluded that sequential, partial, enhanced, and total integration positively affected student achievement in both disciplines, with a generally more positive effect on the academic achievement in science than in mathematics. Only one type of integration--parallel integration--appeared to have a negative effect on both disciplines because unlike the others, parallel integration involved mathematics and science learning in related, but separate, discipline-specific lessons. Collectively, these results appear to indicate that explicit science and mathematics connections enhance student learning in both disciplines.

When Westbrook (1998) explored the connections that ninth-grade students made between traditionally segregated mathematics and science concepts, the students were randomly assigned by the school computer to two academically equivalent groups: an integrated back-to-back algebra and physical science class (SAM9), the treatment group of 26 students, and a non-integrated physical science-only (PSO) and Algebra I class, the comparison group of 22 students. This eight-month-long integrated curriculum was the result of a collaborative effort of the schools’ physical science and mathematics teachers. The results presented in this study pertained to the topics of slope and density--the first integrated investigation in the course. In the study, students developed concept maps at
three points in the learning cycle of each investigation (exploration, invention, and expansion). The study found that the students in the treatment group demonstrated a greater number of connections of mathematics and science concepts than their peers in the discipline-specific class (p. 90). In essence, six of the 26 SAM9 students connected density to slope and 10 students linked density to graphing. In comparison, only one PSO student identified a relationship between density and slope, while three students referred to a connection between density and graphing.

One of the unexpected results of the aforementioned study was the fact that the students in the treatment group developed a compartmentalized view of science and mathematics content. That is, although they were able to make more linkages between mathematics and science on concept maps than their peers in the discipline-specific course, students in the treatment group placed the terms related to mathematics and science in different locations on the concept maps. This apparent discrepancy between the predicted and actual outcomes was explained by the “sorted” approach of the two instructors to content presentation. In the density/slope investigation, the mathematics teacher taught slope and graphing, whereas the science teacher taught the concept of density. Consequently, these teachers maintained their “traditional teaching territories and conceptual complexity” (p. 84), making it more difficult for students to develop an integrated framework with which to think about mathematics and science concepts (91). Other students experienced the “division of labor along traditional, disciplinary lines,” but in less explicit, obvious ways. It is unclear how students would have reacted if the teachers had switched their roles or had not revealed their specialty disciplines.
Whereas Westbrook (1998) focused on the impact of integrated lessons on ninth-grade students, Judson and Sawada (2000) studied the integration of statistical concepts and techniques in an eighth-grade science course, with a high level of integration determined by the likelihood of a random classroom visitor being able to identify the subject of the lesson as either science or mathematics. In the study, Mr. J., a science teacher, implemented inquiry-oriented statistical activities involving data-generating techniques (with graphing calculators). As a result, his students significantly outperformed their peers in the comparison group on a statistics exam. In this case, a more traditional science teacher taught the students in the comparison group, whereas both the treatment and comparison groups were taught by a mathematics teacher whose teaching style was described as not being inquiry-based.

Prior to the study, Mr. J. had gained practical hands-on experiences in integrating science and mathematics through the use of technology at a month-long professional development workshop, organized by the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) and funded by the National Science Foundation (NSF). The activities in the summer workshop emphasized the inter-connectedness of science and mathematics in school lessons and promoted inquiry teaching. As a result, Mr. J. enhanced his understanding of and appreciation for student-centered classrooms and viewed the workshop activities as having been “just in time” for the integration of mathematics and science in his lessons (p. 423). This result concurs with the recommendations of Roth and Givvin (2008), whose analysis of the TIMSS 1999 Video Study of mathematics and science lessons in five high-achieving countries and the United
States, included analyses of professional development opportunities for teachers to strengthen their content and pedagogical knowledge and collaborative opportunities to develop coherent science content story lines for lessons.

In addition to the studies of the impact of integrated curricula on middle school (Westbrook, 1998) and high school students (Judson & Sawada (2000), the literature presents evidence of similar studies in other settings (e.g., Arnett & Van Horn, 2009; Hurley, 2001). For instance, Arnett and Van Horn (2009) studied the experiences of first-year college students with remedial math skills enrolled in an interdisciplinary course (learning-community course) that taught mathematics content in the context of science. The students in the comparison group attended both algebra and general biology classes three times a week for an hour in addition to a biology laboratory for one two-hour block per week. For the students in the learning community, one of the three algebra hours followed the two-hour biology laboratory time, creating a three-hour algebra-biology block. Both mathematics and biology instructors were present in the classroom for each algebra-biology block.

The results of this study indicated that the students’ final grades in intermediate algebra were significantly higher for students in the math class linked with biology than the unlinked class, whereas no significant differences were found in students’ final biology grades. Dispositional surveys showed that 75% of the learning-community had positive attitudes toward math at the end of the semester, compared to 38% of students in the unlinked intermediate algebra course. Eighty-six percent of the learning-community students found it helpful to use biology data to do algebra, and 100% acknowledged that
the presence of a mathematics instructor in the biology lab was important. In contrast, the comparison group of students had difficulty envisioning how mathematics and biology could be linked and suggested that “they might understand the math topics if they were ‘put in perspective’ with biology” (p. 33).

In summary, the results of empirical studies about the impact of integrated mathematics and science education on learning support integration, since there is evidence that integrated education can enhance student learning, student motivation for learning as well as teacher learning. The literature suggests that integrated mathematics and science contexts provide students with learning experiences that are more meaningful than those offered through traditional contexts of subject-specific lessons. However, without a strong knowledge base for effective teaching of mathematics and science connections, mathematics and science teachers may find it challenging to teach two subjects--mathematics and science. For this purpose, future efforts to support integrated instruction should remain sensitive to teachers’ past experiences with integration and consider teachers’ needs to prepare for effective integrated instruction. With the support of professional development leaders and colleagues, mathematics and science teachers will be able to plan and implement lessons involving meaningful connections of mathematics and science.

**Recent Efforts to Integrate Mathematics and Science**

The historical analysis of the literature related to mathematics and science integration by Berlin and Lee (2005) involved about 800 documents published between 1901 and 2001. Most documents surveyed by Berlin and Lee appeared in the 1970s,
1980s, and 1990s, with the largest number of publications in the 1990s (p. 18). Berlin and Lee (2005) and Pang and Good (2000) suggest that documents published before 1990 were mostly instructional activities. According to Pang and Good (2000), “There was a profound lack of research documents” (p. 73) on the integration of these two disciplines published until about 1990. Collectively, these findings highlight the need for further exploration of integrated curricula and instruction.

Despite the constant calls for curricular integration (Pang & Good, 2000, p. 78), the implications of integrated education for teachers have largely remained understudied (e.g., Berlin & Lee, 2005; Lehman, 1994). In recent years, some studies focused on the integrated instruction in teacher preparation programs (Berlin & White, 2012; Frykholm & Glasson, 2005; Koirala & Bowman, 2003) and professional development workshops (Basista & Matthews, 2002; Berlin & White, 2012). However, today, there continues to be a significant shortage of studies that examine teachers’ practices and contexts that are conducive to successful curricular integration. As suggested by Berlin and Lee (2005), “Although several theoretical integration models have been posited in the literature published from 1990-2001, more empirical research grounded in these theoretical models is clearly needed in the 21st century” (p. 15).

**Related to Pre-Service Teachers**

The literature includes examples of studies related to integrated mathematics and science education in teacher preparation programs (e.g., Berlin & White, 2012; Koirala & Bowman, 2003). These studies reveal important implications of activities focusing on the integrated instruction for pre-service teachers enrolled in courses related to mathematics
and science education. For example, Lewis, Alacaci, O’Brien, and Jiang (2002) analyzed 23 projects developed by pre-service elementary school teachers in a science education course that employed a project-based science (PBS) approach for mathematics and science integration. These educators analyzed and assessed teacher projects based on the five forms of integration described in the Lonning and De Franco continuum model (1997). The study found that pre-service teachers made a significant number of basic mathematical errors in their projects, which were frequently situated in contexts underutilizing data representations and data analysis. In general, the pre-service teachers experienced difficulties in integrating mathematics and science. Thirteen percent of all of the projects failed to connect mathematics to the investigation question, and many projects showed only a minimum use of mathematics.

These results cast doubt on pre-service elementary school teachers’ content knowledge of mathematics in problem-based contexts, and emphasize the general need for improved experiences with the learning of mathematics content in pre-service teacher education programs. In a school setting, practicing teachers’ inadequate understanding of basic mathematical concepts and procedures may have a negative effect on the quality of integrated instruction and student learning of mathematics. Thus, the results of this study reveal the need for a continued support of prospective teachers during methods courses in their development of knowledge needed for a successful integration of the two subjects.

The struggles of pre-service teachers with the integration of mathematics and science were also revealed in the study by Cady and Rearden (2007) who examined the beliefs about knowledge, mathematics, and science of K-8 pre-service teachers enrolled
in a content methods course. This course exposed prospective teachers to student-centered instructional methods in mathematics and science. They also developed lesson plans that integrated mathematics and science. The study identified pre-service teachers’ epistemic beliefs about mathematics and science teaching and learning. In addition, the study assessed pre-service teachers’ ability to write lessons that integrated mathematics and science. The participants completed a Student Information Sheet, an anxiety-rating scale, open-ended mathematics and science responses, the Learning Context Questionnaire (administered on the first day of class), a mathematics autobiography, multiple class assignments, and an integration of mathematics and science survey (administered on the last day of class).

The findings of this study revealed that, on the first day of class, 75% percent of pre-service teachers in the study expected the teacher educator to present information for them to memorize and that alternate viewpoints were difficult for them to see. They viewed the study of mathematics as being a passive activity, but supported hands-on, real-world and problem-solving activities. The researchers also found a high level of math anxiety among the pre-service teachers (34% percent indicated high levels of math anxiety, compared to 7% percent in science). For many participants, the feelings of inadequacy in mathematics began with tracking in middle school. However, science-related terminology (e.g., “inquiry,” “discovery,” or “investigating”) created a more positive view of mathematics learning among participants.

Throughout the course, the quality of the integrated lessons varied. The pre-service teachers struggled with the design of lessons that integrated mathematics and
science. Many lessons were not student-centered, and the examples of mathematics and science integration presented by pre-service teachers were described as “contrived” and lacking “congruence between the two concepts selected” (p. 243). This study also suggested:

Activities in the methods course focusing on both math and science, with each content area articulated, could assist preservice teachers with viewing concepts more holistically. Without those experiences, they seem to view each subject area as independent … More practicum experiences where mathematics and science were integrated would also assist preservice teachers with viewing firsthand the integration of these two subject areas. (p. 243)

These types of integrated experiences could be provided by mathematics and science educators in methods courses to enable pre-service teachers to begin to learn about the integration of mathematics and science and to enter the teaching profession with prior classroom experiences in integrated instruction.

Frykholm and Glasson (2005) studied pre-service secondary mathematics and science teachers’ experiences with science and mathematics integration, their individual perceptions of the subject area content and pedagogical content needed to connect science and mathematics, and how contextually-based mathematics and science connections in the coursework influenced their thinking and practices during student teaching. The participants were enrolled in a two-semester methods course sequence prior to their student teaching experience. This study involved multiple data sources, which included: curriculum projects developed by the students, audio-taped large-group discussions,
audio-taped small-group collaborations, written responses to various questions posed by the instructors, journal entries, audio-taped group presentations, lesson plans, and classroom observations completed during the student teacher experience.

Data from two one-year cohorts who participated in this study over a two-year period (23 in science and 42 in math) suggested that the study participants were initially “concerned about their lack of content knowledge in whichever field was not their primary content area” (p. 133), which made them feel uncomfortable about the prospect of completing collaborative projects in the course. These prospective teachers “believed that they were supposed connect mathematics and science in their teaching, but they had seldom seen or experienced such models of instruction” (p. 137). Thus, this study gave these teachers an opportunity to experience instructional models they could implement one day in their own classrooms.

Over the course of this study, the study participants grew in their knowledge of the connections between mathematics and science. This study also revealed the positive effect of the collaborative classroom interaction between the study participants on their perception and understanding of mathematics and science integration. Further, student teaching experiences that followed the methods course revealed new observations and reflections regarding integrated practices made by the study participants when they implemented lessons previously developed in the methods course in their classrooms.

This study highlights the need for future teachers to develop prerequisite skills, content knowledge, and experiences necessary for integrated science and mathematics teaching and learning within the context of the teacher preparation process (p. 139). As
revealed in this study, prospective teachers may support integration but lack confidence in their ability to integrate mathematics and science. Thus, the focus on the kinds of instruction that connects science and mathematics in the methods courses could assist prospective teachers in the development of stronger knowledge bases to implement integrated instruction in their future classrooms.

Analogous to the study by Frykholm and Glasson (2005), Koirala and Bowman (2003) examined the perceptions about and experiences of prospective teachers enrolled in a methods course with mathematics and science integration. This study involved a team-taught integrated middle level mathematics and science methods course, rather than a course for prospective secondary teachers. It also examined the effect of the course on teaching prospective teachers how to connect mathematics and science. The data collected from three groups of pre-service teachers over a three-year period revealed that pre-service teachers appreciated the emphasis on integration utilized in the course, although they expressed frustration when concepts did not integrate easily. The study also suggested that the pre-service teachers’ understanding of integration was enhanced as a result of the course (p. 145).

Most pre-service teachers began the course expecting integration of mathematics and science to be “a blending of the two subjects, so that no seams appear” (p. 151). In this view, integration was perceived as a match rather than merely an alignment of these disciplines in classroom activities. Consequently, pre-service teachers’ expectations and understandings of the term integration led to disagreements about integration in activities in the study. The course instructors attempted to convince their pre-service teachers “that
the integration of mathematics and science does not mean that the two subjects have to match” (p. 151). They assisted them in coping with the conflicts about the nature of integration by: a) allowing for many questions to be asked and answered in class, b) sharing their own struggles in selecting or designing curricular materials for the course, and c) trying to help teachers realize the many reasons why integration could be considered superior to other methods, despite a possible lack of seamlessness in the presentation of topics in these disciplines.

Although pre-service teachers recognized the benefits of mathematics and science integration and were enthusiastic about having observed models of integrated instruction in the methods course, once in the classroom, they had limited opportunities to practice integration during their student teaching due to a lack of team-teaching at their assigned schools or due to difficulties with integrating selected mathematics and science topics. Thus, the appreciation, the tension, and the absence of integration were exposed as issues likely to be noticed in integrated mathematics and science courses, and these issues were found to be important for teachers and instructors when they teach integrated courses and lessons in mathematics and science (p. 152).

Similar to pre-service teachers in studies by Frykholm and Glasson (2005) and Koirala and Bowman (2003), pre-service teachers in a study by Berlin and White (2012) clearly valued integration (p. 20). This study also revealed common challenges with the implementation of integrated instruction faced by prospective teachers as they attempted to teach integrated lessons during their fieldwork experiences. Unlike the researchers in the two aforementioned studies, Berlin and White conducted an in-depth analysis of the
attitudes and perceptions about the integration of mathematics, science, and technology education of prospective teachers seeking certification to teach mathematics in grades 7-12, science in grades 7-12, and technology education in grades K-12.

In this study, a 20-item, five-point semantic differential survey was administered to 81 teachers enrolled in a team-taught Integrated Mathematics, Science, and Technology (MSAT) Program. This six-course program comprised three integrated content courses: mathematics, science, and technology, and three integrated pedagogy courses: exploring the goals, conceptions, and philosophical backgrounds of each discipline; assessment and instructional strategies appropriate for integrated education, and problems and practices in reaching all students in integrated contexts. The study measured the impact of the program on pre-service teachers’ attitudes and perceptions related to mathematics, science, and technology education.

Berlin and White (2012) found no significant changes in pre-service teachers’ perceptions of science, mathematics, and technology education integration; the integrated curricula were valued equally high before and after the program. However, many pre-service teachers reported finding integrated content to be more difficult to implement than traditional content. Several challenges with integration were identified, including time constraints, the need to collaborate with other teachers, content knowledge, among others. This outcome further demonstrates the need for teacher educators to support pre-service as well as in-service teachers in their efforts to integrate mathematics and science. This support will require educators to “deal specifically with the aspects of complexity, inefficiency, and difficulty” associated with integrated instruction (Berlin & White, 2012,
Overall, it is critical that integrated instruction efforts involve teamwork and collaboration of colleagues in multiple subject areas (p. 28).

**Related to In-Service Teachers**

There are very few empirical studies that focus on the nature of instruction in science and mathematics integrated contexts for in-service teachers. Some of the studies that examined integrated instruction in teacher preparation programs reported findings related to the challenges of mathematics and science integration in the classroom (e.g., Berlin & White, 2012; Koirala & Bowman, 2003). The literature presents only a few examples of studies focusing on the integration of mathematics and science by in-service teachers in elementary schools (Douville, Pugalee, & Wallace, 2003), middle schools (Huntley, 1999; Stinson, Harkness, Meyer, & Stallworth, 2009), secondary schools (Austin, Converse, Sass, & Tomlins, 1992), and universities (Arnett and Van Horn, 2009). Despite “a tremendous proliferation in the number of documents related to the topic of integrated science and mathematics education from the 1970s through the 1990s” (Berlin & Lee, 2005, p. 19), the literature continues to portray integration as a desirable but largely unfulfilled instructional goal (Pang & Good, 2000).

Targeting integrated practices at middle school level, Huntley (1999) conducted observational case studies of four middle school teachers, who attempted to dissolve the “disciplinary boundaries between mathematics and science” and integrate the “teaching and learning of mathematics and science to the extent that a visitor observing the class would be unable to distinguish whether the class was a mathematics class or a science class” (p. 60). In this context, lessons involved both mathematics and science, and
ignored the traditional disciplinary boundaries with a goal to promote “students’ acquisition of conceptual rather than only procedural knowledge” (p. 66). The study analyzed classroom practices and curricular materials of the participating teachers through the lens of the continuum model, and analyzed teachers’ beliefs as well as the mathematical and scientific tasks students engaged in during classroom instruction.

Huntley’s (1999) analysis of field notes and classroom observations revealed full integration of mathematics and science topics in the classroom only to a limited extent, despite the substantial teaching experience of the study participants and a five-year history of integrated teaching at the school. The learning tasks designed and implemented by the teachers required only a low cognitive demand from the students, possibly due to directive or modeling teaching approaches, which gave students limited opportunities to engage in activities promoting the acquisition of conceptual rather than procedural knowledge (p. 66). “Students had little opportunity to conjecture, hypothesize, or reason about mathematics or science,” and teachers maintained intellectual authority during all of the observed lessons (p. 64). When asked to reflect upon their experiences with integration, teachers referred to a lack of instructional models for integrated education, limited school funding, and a lack of departmental and administrative support of integration as possible causes for their weak content and process integration attempts. The authors further suggest, but do not provide evidence for, improved teacher collaboration and instructional and curricular models as possible directions for future teacher education programs.
Austin, Converse, Sass, and Tomlins (1992) describe a year-long project conducted by the Texas Higher Education Coordinating Board and designed to bring secondary science and mathematics teachers together to write teaching units that coordinated or integrated science and mathematics (p. 64). A total of 15 science teachers and 19 mathematics teachers enrolled in a fall semester course on mathematics and science and jointly developed 13 integrated curricular units. In the course, teachers participated in laboratory demonstrations, which modeled the integration of mathematics and science by teaching science concepts, with mathematics being used to analyze or model what was observed (p. 64). During the spring semester, the integrated teaching units developed by teams consisting of 2-4 teachers in the fall and winter semesters were field tested in the teachers’ classrooms.

Aside from producing 13 integrated teaching units, the study found the following three results: 1) the project helped mathematics teachers to become more aware of science topics that could help students learn mathematics concepts more productively; 2) the project enabled the science teachers to become more aware of mathematics topics related to the quantitative aspects of science, and 3) the project created opportunities for teachers to work together in a collaborative setting. The teachers had to overcome significant differences in how they solved problems based on their cross discipline backgrounds, how they used mathematics, and how mathematics and science textbooks used mathematics. However, despite these multiple findings, it remains unclear if similar results could be replicated without participation in a semester-long college course, or if
similar teacher collaboration could be achieved in other ways. In addition, it is unclear if a \textit{full} integration of mathematics and science was the goal of “integration.”

To explore teachers’ perceptions of mathematics and science integration, Stinson, Harkness, Meyer, and Stallworth (2009) and Meyer, Stinson, Harkness, and Stallworth (2010) analyzed middle grades science and mathematics teachers’ responses to open-ended, instructional scenarios. Thirty-three teachers who participated in this study first reflected on the scenarios and then provided examples of their own integrated lessons. The results indicated that teachers used varying characterizations of integration in their responses and that they were more likely to identify common content activities as being integrated rather than those that were less common and presented less explicitly. This finding suggested that a continued emphasis on improving teachers’ content knowledge was an essential prerequisite to future mathematics and science integration attempts (p. 153).

In light of the limited number of studies that have focused on teachers’ practices of integrated instruction, it is essential to study integrated instruction more extensively in diverse contexts. Past research has linked standardized tests (Dossey, 1991; Isaacs et al., 1997; Czerniak et al., 1999), teacher knowledge (Roth McDuffie & Morrison, 2008; Steen, 1991), teacher beliefs (e.g., Lehman & McDonald, 1988; Lehman, 1994), school-day scheduling (Jacobs, 1989; Austin et al., 1992; Shea, 1995), teacher training (Mason, 1996; Roebuck & Warden, 1998; Steen, 1991) and teacher collaboration (Beane, 1995; Roth McDuffie & Morrison, 2008) to integrated teaching. However, the literature lacks extensive research on teacher practices related to integrated instruction in K-12.
classrooms. More studies are needed to better understand the nature of the connections of mathematics and science that teachers make in the classroom as well as to develop effective instruments for the assessment of these connections and related instructional practices.

**Related to Professional Development**

The literature provides several examples of successful professional development programs whose focus on science and mathematics education provided teachers with opportunities to deepen their knowledge of interdisciplinary education (e.g., Basista & Matthews, 2002; Judson & Sawada, 2000). For instance, Basista, Tomlin, Pennington, and Pugh (2001) studied the impact of professional development on the teachers’ understanding of physical science and mathematics integration. The program consisted of a half-day workshop for school administrators, an intensive four-week summer institute for teachers, and academic follow-up seminars and classroom visitations throughout the school year (three visits). During the summer institute, teachers engaged in activities that were team-taught by mathematics and science educators. The study employed inquiry and cooperative learning methods to model exemplary teaching and learning in contexts that expose the potential interdisciplinary connections of science and mathematics.

Based on the analysis of pre- and post-institute teacher questionnaires, reflective discussions, journals, portfolios, interviews, and classroom observations, the research team concluded that activities in this professional development program enhanced teachers’ content knowledge in science and mathematics and improved their pedagogical
understanding of integrated instruction. In addition, the program appeared to increase teacher efficacy, to support teachers in implementing summer institute practices in their classrooms throughout the year, to enhance the administrators’ understanding of the challenges involved in implementing integrated lessons, and to provide opportunities for teachers to collaborate and coordinate within and across grade levels (pp. 623-624). However, the program was limited to physical science and mathematics and did not provide evidence to support integration in other mathematics and science contexts. In addition, the follow-up post-summer-institute activities, which occurred throughout the academic year, were not conducted on a regular basis. Thus, designing and implementing similar models with a broader range of learning contexts is essential.

**The GK-12 Program.** Beamer, Van Sickle, Harrison, and Temple (2008) studied the long-term effect of the NSF-funded GK-12: Lowcountry Partners for Inquiry Program on the constructivist science teaching methods of four middle school science teachers from a large, primarily urban school district in the United States. According to the official GK-12 website (www.gk12.org), since its inception in 1999, the Graduate STEM Fellows in K-12 Education (GK-12) Program has funded over 200 similar programs in more than 140 different universities throughout the United States and Puerto Rico. By placing science, technology, engineering, and mathematics (STEM) graduate or advanced undergraduate students (Fellows) in K-12 mathematics and science classrooms, the GK-12 Program provided Fellows with opportunities to share their knowledge of modern scientific research with their partner teachers, students, and the school
community. Over the years, more than 10,000 K-12 teachers have been involved in GK-12 Programs in at least 5,500 different schools with over half a million K-12 students.

In a study by Beamer, Van Sickle, Harrison, and Temple (2008), the GK-12 teachers completed over 200 hours of professional development in constructivist teaching methods over a three-year period, gaining hands-on experiences and real-world perspectives from program-related activities. Constructivist teaching methods engage students in active learning processes (Beamer et al., 2008; Moussiaux & Norman1997; Tolman & Hardy, 1995), thus, this GK-12-related study focused on the following five parameters of constructivist learning and teaching: (1) personal relevance (where students create meanings); (2) scientific uncertainty (where students view knowledge as originating from theory-dependent studies, in social contexts that evolve with the human experience); (3) critical voice (developed by students for the purpose of classroom dialogue); (4) shared control (with the emphasis on students’ class input and action), and (5) student negotiation (where students work together to create new understandings).

Based on the results of the classroom observations, teacher interviews, and Constructivist Learning Environment Surveys (CLES) that were conducted two years after the completion of the GK-12 program, the study found a significant increase in the teachers’ use of constructivist practices after they completed the program.

The literature contains evidence in support of GK-12-related effectiveness of professional development opportunities for mathematics and science teachers. The results suggest that the GK-12 Program’s model not only improves the Fellows’ communication skills (Mitchell et al., 2003; Mumba, Chabalengula, Moore, & Hunter,
2007), but also enables in-service science teachers to sustain their understanding of constructivist learning (Beamer, Van Sickle, Harrison, & Temple, 2008) and enhances their content knowledge (Mitchell et al., 2003). However, there is currently a shortage of empirical studies examining the impact of GK-12 programs on teaching in contexts that integrate mathematics and science, particularly studies that encourage Fellows to co-teach mathematics and science in integrated settings.

The literature suggests that learning in context provides both adults and children with opportunities to form meaningful, knowledge-rich understandings of mathematics and science (e.g., Barnett & Hodson, 2001; Bransford, Brown, & Cocking, 1999; NRC, 2005). For teachers, the development of pedagogical context knowledge for integrated teaching can be situated in the classroom. These results suggest that the GK-12 Program could serve as a model for improving teachers’ knowledge of mathematics and science integration by providing meaningful learning opportunities for teachers and students in authentic, integrated contexts. The GK-12 model not only provides professional development for teachers, but it also encourages teachers to engage in meaningful collaborations with their colleagues and visiting scientists (Fellows). When teacher learning is situated in the context of one’s own classroom, these conditions can lend themselves to productive learning outcomes.

**Summary**

The literature presents examples of extensive efforts on the part of the academic community to incorporate interdisciplinary connections and integrated instruction into mathematics and science education (e.g., Berlin & White, 2012; Bosse et al., 2010). In
recent decades, the pressures of standardized testing and accountability have affected the efforts to pursue mathematics and science integration (Berlin & White, 2012). However, “the squeeze on instructional time increasingly leads educators to consider mathematics and science integration in an effort to be more efficient and effective” (Stinson et al, 2009, p. 153).

If the teaching and learning outcomes in science and mathematics are to improve in contexts that integrate these disciplines, how can such enriched contexts become more commonplace in today’s schools? One answer to this question is obvious: teachers need to apply their disciplinary knowledge to teach each subject and they need to be supported in their efforts to integrate instruction. Without the pedagogical expertise and support of well-qualified teachers who understand how and why to integrate, the integrated learning contexts will remain impracticable. Teachers need to be knowledgeable about integrated teaching methods, because expecting them to “adequately develop and present integrated or thematic curriculum/instruction is condemning them … to areas beyond their licensure” (Lederman & Niess, 1997, p. 58).

Obviously, the integration of mathematics and science is a demanding teaching objective, even for the most experienced educators. The literature is full of evidence of barriers to effective integration and warnings about the consequences of weak instruction, including the following: the development of weak content knowledge in both disciplines (Lederman & Niess, 1997), fundamental differences in the knowledge structure of mathematics and science (Isaacs et al., 1997; Steen, 1991), content compromises (Isaacs et al., 1997; Lederman & Niess, 1997; Steen, 1991), state proficiency and standardized
tests (Czerniak et al., 1999; Dossey, 1991; Isaacs et al., 1997), teacher knowledge for successful integration (Roth McDuffie & Morrison, 2008; Steen, 1991), teachers’ understanding of and beliefs about integration (Lehman, 1994; Lehman & McDonald, 1988), the structure of the school day (Austin et al., 1992; Jacobs, 1989; Shea, 1995), not enough evidence that an integrated curriculum is more effective than a traditional curriculum (Czerniak et al., 1999), the lack of focus on integration in teacher preparation programs (Mason, 1996; Roebuck & Warden, 1998; Steen, 1991) and university teaching (Meier, Nicol, & Cobbs, 1998), and insufficient time in the curriculum to build connections (Beane, 1995; Roth McDuffie & Morrison, 2008). Thus, it follows that future efforts to integrate science and mathematics will require effective and efficient teaching strategies that focus on the learning in science and mathematics.

Teacher knowledge of instructional practices that assist students in making meaningful connections between mathematics and science is critical to a successful integration of these two subjects. According to Roth and Givvin (2008), the effectiveness of mathematics and science instruction in the United States continues to fall short of what is practiced in countries with a higher academic achievement in these disciplines. When comparing mathematics and science teaching in the United States to five higher-achieving TIMSS countries (the Czech Republic, Australia, Japan, Hong Kong, and the Netherlands), Roth and Givvin found mathematics teaching in the United States to be limited to isolated algorithms and facts, and science teaching to be lacking a core pattern. Unlike their foreign colleagues, science teachers in the United States present science content as a collection of facts, rather than a connected system of ideas. Teachers in
higher-achieving countries also surpassed their colleagues from the United States in their ability to implement “making connections” problems without focusing solely on procedural learning (p. 25).

Despite the large variety of learning opportunities available to in-service teachers, including professional development activities, graduate studies, conferences, fieldtrips, teacher collaborations, and reflections upon one’s own practice, the improvement of one’s teaching appears to be highly complex. Weiss, Banilower, McMahon, and Smith (2001), who studied mathematics and science teachers’ needs and perceptions about their preparedness for teaching, point to the lack of free time during the school day to correlate one’s teaching with that of the other instructors. In addition, only less than a third of teachers in the study reported changing their teaching practices through professional development (p. 60). In science, only 20% of K-4, 27% of 5-8, and 19% of 9-12 teachers reported helping their students to see connections between science and other disciplines on a daily basis (p. 80). Similarly in mathematics, only 23%, 17%, and 12% of teachers in the respective grade categories reported helping students to connect mathematics with other disciplines. These results may be indicative of teachers’ unfamiliarity with or lack of experience with integrated instruction, materials, and learning settings.

The enhancement of mathematics and science education at the middle school level is important to student learning today. However, the lack of disciplinary and/or pedagogical knowledge in the two subjects could prevent teachers from attempting to integrate instruction, and could become an obstacle to productive learning. How, then, can teachers provide opportunities for their students to make connections of mathematics
and science? What are some of the most effective and efficient approaches to integrated instruction in the classroom? What types of conditions are conducive to learning about the teaching of integrated lessons? These questions continue to be important to the future of integrated teaching and learning, but research has yet to answer them satisfactorily.

Stigler and Hiebert (2004) state that “analysis of classroom practice … gives teachers the opportunity to analyze how teaching affects learning and to examine closely those cases in which learning does not occur” (p. 16). The literature also suggests that professional development activities can enhance mathematics and science teachers’ content knowledge (Mitchell et al., 2003), including the knowledge of mathematics and science integration (Basista, Tomlin, Pennington, & Pugh, 2001). Thus, it follows that future attempts by the education community to support teachers in their efforts to integrate instruction involve opportunities for teachers to experience integrated teaching in their own classrooms. It is also important that future research continues to explore how teachers “develop the craft and content knowledge necessary for guiding students through authentic, rich, integrated experiences in science and mathematics” (Frykholm & Glasson, 2005, p. 131). Guided by research, the education community will be able to continue to assimilate integration models, materials, and practices most appropriate for mathematics and science education.
CHAPTER 3 - METHODOLOGY

“Qualitative research seeks to probe deeply into the research setting to obtain in-depth understandings about the way things are, why they are that way, and how the participants in the context perceive them. To achieve the detailed understandings they seek, qualitative researchers must undertake sustained in-depth, in-context research that allows them to uncover subtle, less overt, personal understandings”
(Gay, Mills, and Airasian, 2009, p. 12).

Research Design

To understand middle school teachers’ practices related to mathematics and science connections in the classroom, the extent to which these practices exemplified mathematics and science integration, and teacher perceptions and attitudes about integrated instruction, this study implemented a qualitative research design with classroom observations and teacher interviews. An attitudinal teacher survey and artifacts were collected to provide additional insights about teachers’ perceptions and attitudes toward integration.

Classroom observations were nonparticipant observations to optimize the researcher’s ability to observe and record teacher behaviors with minimum impact of a visitor on teachers and students (Gay, Mills, & Airasian, 2009). Each observation was followed by a debriefing interview with the teacher. These interviews were semi-structured to maintain the focus on mathematics and science connections and integration, while also addressing details emerging from individual lessons. Semi-structured interviews with each teacher were also conducted before and after the study.

The interpretation of emerging regularities in the data (Bogdan & Biklen, 2007) was guided by the literature, including studies of Davison, Miller, and Metheny (1995), Huntley (1998, 1999), Hurley (2001), and Lonning and De Franco (1998). The research
questions, especially Question 1a, were guided by the findings of Frykholm and Glasson (2005), who proposed the use mathematics and science connections as “levers to promote integrated mathematics and science instruction” (p. 127).

**Setting**

This study was part of a GK-12 research project at a large university in northeastern United States. Over the past fifteen years, the National Science Foundation (NSF) has funded and managed over 200 similar projects throughout the United States and Puerto Rico, enabling graduate students (Fellows) in science, technology, engineering and mathematics (STEM) disciplines to interact with students and teachers in K-12 classrooms and share their knowledge of STEM research. These projects have also provided K-12 mathematics and science teachers with opportunities to work alongside expert scientists and deepen their knowledge of student-centered and inquiry-based instruction.

From 2007 to 2013, the program at this university involved five public school districts, with at least two districts participating in program activities in any particular year. Each year, districts nominated pairs of mathematics and science teachers for the program based on teachers’ professional experience, tenured teaching status, ability to collaborate with colleagues, and a general interest in the program. Teachers who accepted the district nomination returned signed agreement forms to the program management team prior to the start of the program’s summer activities (see Appendices A and B for teacher and school district contracts, respectively).
Teachers received stipends from the National Science Foundation for their participation in the program. They were also granted professional credits for their involvement in program activities. The final amounts of NSF-funded stipends varied among individual teachers, ranging between $2,000 and $3,000. The amount of each individual stipend depended on the teachers’ extent of participation.

Past research efforts of three faculty researchers on the program resulted in quantitative and qualitative research findings about the impact of program activities on Fellows and middle school students. These efforts examined Fellows’ communication skills and middle school students’ academic achievement in and attitude about mathematics and science before and after the program. This study focused on the middle school teachers in the program and described their classroom experiences with and views about mathematics and science teaching in the integrated fashion. Despite the lack of a common definition of mathematics and science integration, the unique structure of this program enabled the researcher to study how integration of mathematics and science could be practiced when teachers “intentionally or knowingly make connections” between mathematics and science (Meyer, Stinson, Harkness, & Stallworth, 2010, p. 155).

This study was conducted in the last year of the program with teachers from the only school that participated in the program that year. The program operated on a no-cost extension and was scaled back from its original version. Out of five school districts that engaged in this program’s activities over the years, this school district was the only district that participated each year of the program’s operation. The public school was one
of seven elementary schools in the district. School details provided by the National Center for Education Statistics (nces.ed.gov) for 2010-2011 academic year showed a total enrollment for this school to be 857 students in grades Pre-K through 8. Data for academic year 2011-2012 was not available for review. Student population was reported to be 56% Hispanic, 40% White, non-Hispanic, 2% Asian or Pacific Islander, and 2% Black, with 42% of students eligible for free or reduced-price lunch.

**Description of Program Activities**

Teachers in this study engaged in a variety of mathematics and science activities with an interdisciplinary and integrated focus. These activities are described next.

**Mentoring of Fellows.** As GK-12 participants, teachers provided professional support and mentoring for graduate students, Fellows, who spent two full school days (one full day in this study) in the teachers’ classrooms each week of the school’s academic year. Fellows were paired by the program management team into mathematics-science teams of two Fellows. Each team worked alongside two teachers, one in mathematics and one in science, co-designing and co-presenting weekly lessons in mathematics and science in the teachers’ classrooms. Teachers provided Fellows with an on-sight support in the aspects of lesson design and implementation, district’s curricular goals and objectives, and classroom management, in respective disciplines. The Fellows also shared their expert knowledge of science and mathematics with their partner teachers and contributed innovative ideas in cutting-edge research to the weekly teaching and learning activities in the classroom.
Fellows co-designed and co-presented weekly lessons in their partner teachers’ classrooms. Each lesson was presented to different groups of students throughout the school day. Through this process, teachers had the opportunity to observe new lessons and reflect upon their own practice in the context of these lessons. As partner teachers, teachers assisted their Fellows with the ongoing revisions of content and design of the lessons, particularly in relation to the extent of mathematics and science integration within each lesson.

**Professional development activities.** Each year of the program, teachers and Fellows participated in monthly professional development workshops with the focus on mathematics and science connections. In addition, teachers and Fellows participated in at least two mathematics and science field trips each year with their students (e.g., local mining museum, planetarium, and science center), including one day of workshops and presentations in mathematics and science on the university campus. Teachers and Fellows also participated in training activities in preparation of the field trips and summer activities, including instructional unit lesson planning. Each of the aforementioned activities presented teachers with opportunities to engage in mathematics and science teaching and learning.

The monthly professional development workshops utilized in the academic year 2012-2013 involved mathematics and science activities with an interdisciplinary and integrated focus. For instance, in the October, 2012, workshop, teachers analyzed three lessons suggested by Huntley (1998) as either interdisciplinary (mathematics with science or science with mathematics) or integrated (mathematics and science). The researcher

The 2012-2013 workshops were originally scheduled for the last Thursday of each month. However, due to reasons independent of the study, spring workshops were conducted on January 31, March 7, April 11, April 25 and May 30. The fall workshops occurred as planned on September 20, October 25, and November 29. Changes in the dates of spring workshops had no known effect on the outcomes of the workshops. There were no workshops scheduled or held in June. Instead, teachers and their middle school students participated in mathematics and science workshops and presentations on the university campus on June 7, 2013.

**Study Participants**

This study involved four teachers: one sixth grade mathematics teacher, one sixth grade science teacher, one seventh grade mathematics teacher, and one seventh grade science teacher. The teachers were the only teachers participating in the program during the academic year 2012-2013. All teachers had tenure status and professional experience in classroom instruction ranging between 5 and 14 years. Both seventh grade teachers had successfully obtained master’s level degrees in education in their respective disciplines,
Both sixth grade teachers completed alternate route teaching programs.

According to the data collected in pre-program interviews, none of the four teachers received formal training in mathematics and science integration prior to this study, nor attempted to implement specific integration models or techniques in the classroom. However, the district had provided professional development workshops in interdisciplinary teaching and learning for teachers in the past. The seventh grade mathematics teacher had previously engaged in interdisciplinary activities: a school-wide collaborative project and a physics-themed field trip.

Table 1

*Fellow-Teacher Pairings*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Grade</th>
<th>Year teaching</th>
<th>Fellow</th>
<th>Major</th>
<th>Research</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steve</td>
<td>7th</td>
<td>5th</td>
<td>Adrianna</td>
<td>Molecular Biology</td>
<td>AS-1 DNA Extraction &amp; Sequencing</td>
<td>1st year</td>
</tr>
<tr>
<td>Stacy</td>
<td>6th</td>
<td>6th</td>
<td>Julie</td>
<td>Ecology &amp; Evolution</td>
<td>Soil-plant Interactions</td>
<td>1st year</td>
</tr>
<tr>
<td>Mathematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maria</td>
<td>7th</td>
<td>14th</td>
<td>Adam</td>
<td>Pure &amp; applied mathematics</td>
<td>Magnetoviscosity of ferrofluids</td>
<td>1st year</td>
</tr>
<tr>
<td>Molly</td>
<td>6th</td>
<td>5th</td>
<td>Felicia</td>
<td>Pure &amp; applied mathematics</td>
<td>Elliptic curve Cryptography</td>
<td>2nd year</td>
</tr>
</tbody>
</table>
Each teacher was paired with a Fellow in the respective discipline. The final pairings were based on the district’s curricular objectives and Fellows’ research interests and educational backgrounds (see Table 1 for educational backgrounds of teachers-Fellow pairings). In seventh grade, the mathematics teacher was paired with a Fellow studying applied mathematics, who also held an undergraduate degree in physics education. The science teacher was paired with a Fellow majoring in molecular biology. In sixth grade, the science teacher was paired with a Fellow majoring in ecology and evolution, and the mathematics teacher with a Fellow studying pure mathematics. This Fellow held an undergraduate degree in mathematics education.

**Data Collection**

Data collection activities involved classroom observations of lessons in which teachers attempted to connect mathematics and science and also included teacher interviews. Each teacher presented four lessons and was interviewed once after each lesson. Each teacher was also interviewed and asked to complete an attitudinal survey before and after the study. In addition, the researcher collected artifacts of teacher materials and student work. These artifacts were collected in the context of classroom lessons and as part of selected monthly workshops. All data collection activities occurred in the school.

Since the researcher was invited to observe each lesson, the dates, class periods, content, and location of the lessons were determined by teachers. During lessons, the researcher sat in a discreet location. Each lesson was videotaped with a single camera that was placed strategically away from the view of students. In most lessons, the camera was
placed in the back of the classroom. The researcher relied on the assistance of a graduate student with the videotaping of lessons. The camera position remained constant during most lessons to avoid distractions for students or teachers.

Most lessons occurred in the teachers’ regular classrooms. One lesson was a joint presentation of two sixth grade teachers. This lesson began in the school gymnasium and ended in the school auditorium. A different lesson was also conducted outside the classroom in the school courtyard. The researcher placed a voice recorder in the front pocket of the teachers’ outfit to ensure the quality of sound collected in this lesson.

Post-observation debriefing interviews occurred either on the day of the observation during teachers’ free periods or after school, or within 1-2 days of each observation. When necessary, phone interviews were conducted to ensure a timely response of teachers and the researcher to each lesson. Pre- and post-program interviews were scheduled with each teacher during teachers’ free periods or after school, and conducted in the teachers’ classrooms when students were not present or in other rooms in the school building (e.g., teacher lounge room, copy room). All interviews were audio-taped and transcribed (see Appendix D about the interview protocol).

Attitudinal teacher surveys were administered to each teacher before and after the study and collected after 2-3 days. Most surveys were collected during pre- and post-study interviews or at a time convenient for the teacher. Similarly, most artifacts, including lesson plans, worksheets, student and teacher work, were collected directly after the activity, while some were mailed (and emailed) by teachers to the researcher.
In selected instances, the researcher asked teachers to clarify their responses or to explain specific aspects of their classroom practices. Most of these follow-up activities occurred during subsequent classroom visits and other study-related activities. In one instance, the researcher communicated with a teacher via email.

**Timeline**

This thirteen-month study began in May, 2012 and ended in June, 2013. The researcher conducted pre-study interviews and collected attitudinal surveys in early May, 2012. Classroom observations and post-observation debriefing interviews occurred between February, 2013 and June, 2013. Post-study interviews and attitudinal surveys were conducted in June, 2013. Table 2 presents the schedule of data collection activities.

**Table 2**

**Schedule of Data Collection Activities**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly</td>
<td>TS, TI PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>CO, POD PDW</td>
<td>CO, POD TS, TI</td>
</tr>
<tr>
<td>Stacy</td>
<td>TS, TI PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>CO, POD PDW</td>
<td>CO, POD TS, TI</td>
</tr>
<tr>
<td>Maria</td>
<td>TS, TI PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>CO, POD TS, TI</td>
</tr>
<tr>
<td>Steve</td>
<td>TS, TI PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>PDW</td>
<td>CO, POD PDW</td>
<td>PDW</td>
<td>TS, TI</td>
</tr>
</tbody>
</table>

*Note. TS = teacher survey; TI = teacher interviews (pre or post); PDW = professional development workshop(s); CO = classroom observation(s); POD = post-observation debriefing interview(s).*

Two months prior to classroom observations, the researcher reminded teachers to select lessons for observation. The first lesson observations were then scheduled in February, 2013. Lesson observations in three classrooms, including two mathematics
classrooms, continued until mid-June, 2013. The timeline of these visits depended on instruction in the weeks preceding a weeklong period of standardized testing in late April and early May, 2013. Table 3 presents dates and lengths of teacher interviews and dates of the corresponding classroom observations.

Table 3

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Length and Date of the Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interviews</td>
</tr>
<tr>
<td></td>
<td>Pre</td>
</tr>
<tr>
<td>Maria</td>
<td></td>
</tr>
<tr>
<td>Interview Length</td>
<td>34:21</td>
</tr>
<tr>
<td>Interview Date</td>
<td>5/8/12</td>
</tr>
<tr>
<td>Lesson Date</td>
<td>2/21/13</td>
</tr>
<tr>
<td>Molly</td>
<td></td>
</tr>
<tr>
<td>Interview Length</td>
<td>33:49</td>
</tr>
<tr>
<td>Interview Date</td>
<td>5/9/12</td>
</tr>
<tr>
<td>Lesson Date</td>
<td>2/13/13</td>
</tr>
<tr>
<td>Steve</td>
<td></td>
</tr>
<tr>
<td>Interview Length</td>
<td>32:45</td>
</tr>
<tr>
<td>Interview Date</td>
<td>5/9/12</td>
</tr>
<tr>
<td>Lesson Date</td>
<td>2/11/13</td>
</tr>
<tr>
<td>Stacy</td>
<td></td>
</tr>
<tr>
<td>Interview Date</td>
<td>5/7/12</td>
</tr>
<tr>
<td>Lesson Date</td>
<td>2/13/13</td>
</tr>
</tbody>
</table>

Note. POD = post-observation debriefing interview; Pre = pre-study interview; Post = post-study interview. Interview lengths are presented in hours, minutes, and seconds. For example: 1:02:44 stands for 1 hour, 2 minutes and 44 seconds.

Data Sources

Data sources included the following items: (a) field notes and memos from lesson observations, (b) memos from the monthly professional development workshops, (c) interview transcripts and memos from post-classroom observation debriefing interviews.
and pre- and post-program interviews, (d) teacher and student artifacts, including lesson plans, lesson outlines, worksheets, lab sheets, student work that resulted in the observed lessons, and teachers’ written responses to workshop activities, and (e) selected items from the pre- and post-study attitudinal teacher survey. Table 4 presents a summary of data sources for each research question.

Table 4

Summary of Data Sources

<table>
<thead>
<tr>
<th>Research questions</th>
<th>Data sources</th>
<th>Classroom observations</th>
<th>Teacher interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field notes</td>
<td>Memos</td>
<td>Artifacts</td>
</tr>
<tr>
<td>1a and 1b</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(pages)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 4 5 6 10 12-13 14</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a and 1b 2</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Descriptions of data sources are provided next and presented in the following order: field notes, memos, transcripts, surveys, and artifacts.

**Field Notes** (Questions 1 and 2)

The researcher collected detailed field notes of each classroom observation. These field notes included descriptions of lesson proceedings, teacher practices, teacher
interactions with students, and excerpts of classroom conversations between students and between students and teachers. The researcher also recorded details of informal conversations with teachers. These conversations were sometimes conducted before and after the lessons and after interviews, and were not part of the interviews.

According to Bogdan and Biklen (2007), “in order to do a good study, you must be self-reflective and keep an accurate record of methods, procedures, and evolving analysis” (p. 122). Therefore, in addition to the descriptive material, the researcher also recorded reflective field notes with thoughts, impressions, and ideas developed during or immediately after the observed lessons. Although collected together, reflective and descriptive sections of the field notes were recorded separately. The reflective sections of field notes were designated as observer’s comments with the notation of ‘O.C.’.

Memos (Questions 1 and 2)

In line with the existing guidelines for the analysis of qualitative data proposed by Gay, Mills, and Airasian (2009) and Bogdan and Biklen (2007), the researcher wrote memos about descriptive field notes, observer’s comments, and interview transcripts. Prepared separately from the field notes, these memos were used to organize the ideas and understandings emerging from the data. The memos also included reflections upon the outcomes of activities conducted as part of the monthly workshops and included details of teacher participation in workshop activities.

Interview Transcripts (Questions 1 and 2)

The researcher transcribed audio-recorded data form twenty-four semi-structured teacher interviews. Each transcript was created as a new document. The researcher used
a heading at the start of each interview, which included the time and date of the interview, the name of the teacher being interviewed, and the purpose of the interview (e.g., 1st Post-observation debriefing interview). A new line was started every time a new person spoke. A letter “I” was used to indicate lines spoken by the interviewer and a letter “T” to indicate lines spoken by a teacher.

**Attitudinal Teacher Survey** (Questions 1 and 2)

The researcher adapted the original program’s attitudinal teacher survey for this study. Consequently, seven items from the survey served as sources of additional data. See Appendix E for the complete survey. Teacher responses to one item (3) were used for research questions 1a and 1b. This item provided evidence of past teacher attempts to integrate mathematics and science, including lessons presented as examples of mathematics and science connections. For Question 2, teacher perceptions and attitudes about integrated instruction were studied using data collected in Items 1-7, with Items 5 and 7 used to study teacher attitudes. Table 5 summarizes the survey items. Descriptions of the survey items are provided next.

1) Professional Practices Survey (p. 2 of survey)

For this item, teachers responded to twenty-one statements about their teaching practices using one of the following choices: 1=Strongly Disagree, 2=Disagree, 3=Agree, and 4=Strongly Agree. Due to their relevance to integrated instruction, the statements of particular significance to this study were: 1-5, 7-9, 11, 14-17, and 19-21. The resulting teacher responses provided insights about teachers’ perceptions of pedagogical issues related to mathematics and science
connections and integration. Although these responses were informative, the researcher did not conduct a statistical analysis of the results due to a small sample size. However, the researcher used basic descriptive statistics to present teachers’ responses.

2) MSI Diagram (p. 4 of survey)

Teachers sketched a diagram depicting integration of mathematics and science education. No additional guidelines were provided for this item, giving teachers flexibility to sketch diagrams of their choice.

3) MSI Lesson (p. 5 of survey)

Teachers described their past attempts (lessons) to integrate mathematics and science. In their descriptions, teachers were asked to specify mathematics and science topics in the lesson. This item had a particular meaning to the study because it provided evidence of pre- and post-study perceptions of integrated lessons in teacher practice.

4) MSI Meaning (p. 6 of survey)

Teachers were asked to provide their interpretation of the meaning of mathematics and science integration.

5) Comfort level with math and science content overlap (101-103, p. 10 of survey)

Teachers described their comfort level with teaching content overlap in math and physical science, math and life science, and math and Earth and planetary science by selecting one of the following options: 1=Very
Uncomfortable, 2=Somewhat Uncomfortable, 3=Somewhat Comfortable, or 4=Very Comfortable.

6) MSI Perceptions (pp. 12-13 of survey)

   For this item, teachers responded to eight statements about mathematics and science integration with one the following answers: SD=Strongly disagree, D=Disagree, N=Neutral, A=Agree, and SA=Strongly agree). They also wrote comments in support of their responses. The researcher adapted this item from the Pre-service and Practicing Elementary Teachers’ Perceptions Toward the Integration of Mathematics and Science questionnaire developed by Lehman (1994).

7) Semantic Differential (p. 14 of survey)

   Teachers responded to a rating scale adapted from the semantic differential, Attitudes and Perceptions Related to Integration of School Science, Technology, and Mathematics, proposed by Berlin & White (2012). The original rating scale was designed to measure teachers’ reactions toward pairs of words related to mathematics and science integration. Examples of selected word pairs were: beneficial-harmful, deep-shallow, bad-good, simple-complicated, crutch-tool, or boring-exciting. For each pair of words, teachers placed an X in one of the five blanks, based on how they felt about these words in the context of integration. The five blanks were recorded as 1, 2, 3, 4, and 5, from left to right. However, due to the small sample size of this study, statistical analysis of the data was not expected to be conclusive. This semantic differential described teachers’
perceptions and attitudes about integration and provided additional insights for the data analysis. A teacher feeling strongly about the benefits of integration might be expected to place an X in the leftmost blank (to the right of the word “beneficial”).

Table 5

Summary of Survey Items

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 P</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>2 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. MSI = math and science integration; P = perceptions; A = attitudes.*

**Artifacts** (Questions 1a and 2)

Artifacts from classroom observations and monthly workshops were collected as sources of additional data. Two types of artifacts were collected: teacher artifacts and student artifacts. Teacher artifacts included lesson plans and outlines, teacher-made lab sheets and worksheets for students, lesson handouts, and written responses collected as part of the monthly workshops. Student artifacts included student work generated as part of the lessons. Some artifacts were photographs of student posters and projects generated in connection with the observed lessons and displayed in the classrooms and in the school hallway.

Teacher and student artifacts served as data sources of teachers’ practices regarding connections (Question 1a) and perceptions and attitudes about integration.
(Question 2). The lesson plans submitted for the purpose of this study listed curricular standards, and this detail played an important role in data analysis. Similarly, teacher responses to some of the workshop activities provided important insights into their perceptions of integrated and interdisciplinary instruction.

**Data Analysis**

Data analysis involved at least three readings of each data source. In each reading, the researcher analyzed data by identifying emerging regularities and patterns (Bogdan & Biklen, 2007). The first three readings were guided by the literature, with each reading representing a new phase in the analysis. The first reading (Phase 1) was guided by the integration approaches of Davison, Miller, and Metheny (1995). The second reading (Phase 2) was guided by the continuum models of integration of mathematics and science by Lonning and De Franco (1998) and Huntley (1999), and finally, the third reading (Phase 3) was guided by the integration forms of Hurley (2001). After the third reading, the researcher continued to read the data to ensure that other regularities in the data were identified. The interpretive lens and data analysis procedures, including descriptions of Phases 1, 2, and 3, are described next.

**Interpretive Lens**

Research needs to build upon the existing research base to form common understandings for what it means to integrate mathematics and science (Hurley, 2001; Stinson, Harkness, Meyer, and Stallworth, 2009). Teachers are working without a common definition of mathematics and science integration (Czerniak, Weber, Sandmann, and Ahern, 1999; Pang & Good, 2000), and many terms are being used to refer to
integration, including: connections, interdisciplinary, linked, or fused (Berlin & Lee, 2005, p. 18). Huntley (1999) suggests that “the plethora of terms commonly used to refer to integration complicates this definitional problem” (p. 58). This “plethora of terms” can present a particular challenge to teachers implementing integrated and interdisciplinary instruction, given that these two concepts are not perceived as synonymous by some educators (e.g., Huntley, 1999; Lederman & Niess, 1997). Without a clear meaning of integration, lessons in which teachers attempt to integrate mathematics and science remain difficult to identify as integrated.

The literature presents multiple perspectives on integrated teaching of mathematics and science. These perspectives include integration approaches of Davison, Metheny, and Miller (1995), the continuum of integration of mathematics and science models of Lonning and De Franco (1997) and Huntley (1999), and forms of integration of Hurley (2001). Each of these perspectives provides a different way to interpret integration. For instance, the integration approaches focus on specific components of an activity that could be classified as mathematical or scientific. The evidence of each discipline in an activity is justified when appropriate content, processes or teaching methods are found within it. The continuum models focus on the role that one discipline plays in the learning of the other, with a lack of dominance of one over the other. Huntley (1999) calls these types of roles “synergistic” (p. 59). The forms of integration focus on the coordination of mathematics and science topics within an activity. This final view of integration involves issues of timing, sequencing, and presentation of topics.
The researcher focused on learning about teachers’ efforts to connect mathematics and science in the classroom in an effort to study integrated teaching. Meyer, Stinson, Harkness, & Stallworth (2010) recognize models of integrated mathematics and science instruction as those in which someone is “intentionally and knowingly” making connections (p. 155). Frykholm and Glasson (2005) share this perspective about integration and also propose the use of connections to promote integrated mathematics and science instruction.

Data Analysis Procedures

The data analysis procedures involved ongoing and retrospective analysis procedures. The ongoing procedures involved multiple readings through the data. These procedures enabled the researcher to begin to develop a coding system involving words and phrases representative of topics and patterns in the data (Bogdan & Biklen, 2007). When the data collection activities were finalized, the researcher began the retrospective analysis procedures. These procedures involved new readings through the data, based on the preliminary themes that emerged in the ongoing analysis stage. These additional readings enabled the researcher to consider a full data set and to develop a complete, saturated set of themes in the data. Both procedures are explained next.

Ongoing data analysis. The ongoing data analysis procedures began with the pre-study interview transcripts and surveys, and artifacts collected in monthly workshops. The researcher conducted multiple readings of each data source and began to formulate preliminary ideas about teachers’ perceptions of and past experiences with integrated mathematics and science instruction.
The ongoing data analysis procedures intensified when teachers began to invite the researcher to their classrooms. Each observation resulted in a new set of field notes, memos, interview transcripts, and artifacts. The analysis of these data sources involved at least three readings, and each reading resulted in coding. The first three readings were guided by the study’s theoretical framework, and conducted in three stages: Phase 1, Phase 2, and Phase 3. During this time, the researcher also re-examined data collected before the start of classroom observations. Details of data analysis in each phase are described next.

**Phase 1.** The first reading focused on the evidence of mathematics and science content and processes in the data, and methods used in teaching of these disciplines. This reading was guided by the integration approaches described by Davison, Miller, and Metheny (1995). Each approach to integration (content, process, or method) was coded with a different color. Table 6 presents descriptions of these approaches and colors used to identify each approach in the data. In addition, the researcher used terms ‘math’ and ‘science’ within each color to help distinguish between mathematics and science content, processes and methods. Data that was not connected to these approaches was analyzed for evidence of recurring regularities in later readings.
Table 6

*Integration Approaches of Davison, Miller, and Metheny (1995)*

<table>
<thead>
<tr>
<th>Approach</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content specific integration</td>
<td>Teachers weave together <strong>math and science content</strong> with curriculum objectives from each discipline (p. 228)</td>
<td>Using masking tape on the gym floor to create life-size dinosaurs.</td>
</tr>
<tr>
<td>Code color: Light pink</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process integration</td>
<td>Students make and test hypotheses of <strong>real-life activities</strong> in the classroom; Students conduct experiments, collect and analyze data, report results; Students experience the processes of science and perform the needed mathematics (p. 228)</td>
<td><strong>M&amp;M (TM) activity “What’s in the bag?”</strong> Students formulate a hypothesis about the expected number of M&amp;M’s of each color in a bag.</td>
</tr>
<tr>
<td>Code color: Light blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methodological integration</td>
<td>Teachers infuse <strong>the learning cycle</strong> with the development of teaching and learning models in mathematics; The learning cycle in mathematics is said to provide the learner the opportunity to build upon previous knowledge, respond to it, and develop new experiential structures (p. 229)</td>
<td>Students learn about fraction equivalence using manipulatives (e.g., fraction bars), and then generate a rule or algorithm.</td>
</tr>
<tr>
<td>Code color: Dark pink</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thematic integration</td>
<td><strong>A theme</strong> is developed as a medium with which math and science interact; It is possible for other disciplines to be part of thematic integration (p. 229)</td>
<td><strong>Theme: Oil spills</strong> <strong>Math focus: volume, surface area, cleanup cost</strong> <strong>Science: density, aspects of oil spills; Social studies: economic and social implications of oil spills</strong></td>
</tr>
<tr>
<td>Code color: Black</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* All approaches, descriptions and examples in this table are those of Davison, Miller, and Metheny (1995). The authors do not provide a specific example of methodological integration. The example shown in the table was added by the researcher.
Phase 2. The second reading focused on the extent of integration in mathematics and science presented in the data. For this purpose, the researcher was guided by the continuum of integration of mathematics and science models presented by Lonning and De Franco (1997) and Huntley (1999). Guided by the literature, the researcher considered instances of “science with mathematics” and “mathematics with science” (Huntley, 1999). These instances were described as having “mathematics focus” and “science focus” by Lonning and De Franco. The researcher also considered evidence of “balanced mathematics and science.” Lonning and De Franco placed balanced mathematics and science in the middle of the continuum with intent for each discipline to be grade appropriate and equally relevant and meaningful in the activity or concept. This approach was proposed by Lonning and De Franco and supported by Huntley as “mathematics and science.” Instances of mathematics with science, mathematics and science, and science with mathematics were color-coded as shown in Table 7.

In this reading, the researcher also focused on instances of mathematics and science interacting and supporting each other. This condition was identified by Huntley (1998) as a critical component of “mathematics and science” in the middle of the continuum and considered as a defining element of integration. It was further suggested that integration could involve teaching and learning of more than just the mathematics and science contained within a lesson. For example, Huntley (1998) described a lesson on photosynthesis and surface area of irregularly shaped leaves. This lesson involved a discussion of the relationship between the rate of photosynthesis and the size of leaves in the rain forest, and was identified as integrated. If presented in the study, the researcher
would have coded appropriate instances in this lesson in orange with the code “integration.”

**Table 7**

*The Continuum Model of Lonning and De Franco (1997)*

<table>
<thead>
<tr>
<th>Integration type</th>
<th>Continuum placement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics focus with science as support</td>
<td><img src="image" alt="Math at left, Science at right" /></td>
<td>Mathematics is the primary subject of study with science providing a learning context for math. The focus of the lesson is on mathematics.</td>
</tr>
<tr>
<td>Balanced mathematics and science</td>
<td><img src="image" alt="Math at left, Science at right" /></td>
<td>Lonning &amp; De Franco (1997): Both mathematics and science are the focus of learning.</td>
</tr>
<tr>
<td>Science focus with mathematics as support</td>
<td><img src="image" alt="Math at left, Science at right" /></td>
<td>Huntley (1999): Both mathematics and science are the focus of learning and students learn about the relationship between mathematics and science (integration).</td>
</tr>
</tbody>
</table>

Similarly to Phase 1, data that remained unmatched in the second reading was later categorized in accordance to the extent of regularities occurring within it.
**Phase 3.** The third reading focused on the placement and timing of mathematics and science within a lesson. This reading was guided by five forms of integration developed by Hurley (2001). Hurley first identified these five forms through her extensive meta-analysis of integrated studies of student achievement and ordered them based on the degree of integration they represented. The sequenced form of integration was identified as the weakest and total integration as the strongest. The researcher coded evidence of these forms using the following terms: sequenced, parallel, partial, enhanced, or total integration. The codes matched the terms used by Hurley in reference to each integration form. Table 8 presents descriptions of the forms with the codes.

These five types of integration were identified by Hurley based on a meta-analysis of 31 studies of student achievement. These studies were conducted between 1935 and 1997, and frequently involved interdisciplinary teams of teachers developing curricular modules for classroom implementation. Specifically, the 31 studies examined by Hurley involved interdisciplinary (e.g., McGonagill, 1995; Noto, 1972) and integrated curricula (e.g., Scarborough & White, 1994; Trezise 1995/1996). The development of modules or lessons, interdisciplinary and integrated, involved teams of teachers (e.g., Austin, Hirstein, & Walen, 1997). The researcher classified each lesson based on Hurley’s descriptions of each integration type, and guided by the research studies identified by Hurley in connection with these types. The original descriptions and researcher’s interpretations of these descriptions are presented in Table 8.

As shown in Table 8, Hurley provided a broad description for each integration type. Examples of classroom lessons or instructional details in support of these types of
integration were not provided. For example, for *Sequenced* integration, it was unclear from the description whether the planning and teaching involved a team of teachers (two or more) or one teacher. In this reading, the researcher interpreted *Sequenced integration* to represent a team of teachers who plan and teach a series of mathematics and science lessons or units, with one lesson or unit preceding the other. This interpretation was based on the examination of a research study by Clayton (1989), which was classified as *Sequenced integration* in Hurley’s meta-analysis study. When Clayton (1989) reported the effects of mathematics-science integration on the ninth-grade physical science students, the researcher described the study as involving three teachers per setting. A separate unit on mathematical skills was presented to students prior to the unit on physical science content. *Parallel integration* was interpreted as a collaborative team effort of two or more teachers (at least one mathematics and one science teacher), who planned and taught lessons that complemented student learning of mathematics and science. The lessons would be taught in separate classrooms, and would not always require one lesson to be taught before another lesson. For example, in pre-calculus and physics, these lessons could focus on the teaching of the rate of change in each class. In other words, similar topics could be explored simultaneously in each lesson. This interpretation was based on the study by Allen (1993), which Hurley classified as *Parallel integration*. This study involved two teachers, physics and mathematics, who first co-wrote lessons together for the first six weeks of the academic year, and then met regularly during the school year to continue to coordinate instruction in their courses (physics and pre-calculus).
### Table 8

**Integration Types Proposed by Hurley (2001)**

<table>
<thead>
<tr>
<th>Integration type</th>
<th>Description</th>
<th>Interpretation of instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequenced (SI)</td>
<td>Science and mathematics are planned and taught sequentially, with one preceding the other.</td>
<td>A team of teachers planning and teaching lessons in sequence. This type of integration could be achieved if one teacher taught science lessons and mathematics lessons in sequence (in separate periods).</td>
</tr>
<tr>
<td>Parallel (PI)</td>
<td>Science and mathematics are planned and taught simultaneously through parallel concepts.</td>
<td>A team of teachers planning and teaching lessons in complementary topics. The topics are addressed simultaneously in two or more classrooms.</td>
</tr>
<tr>
<td>Partial</td>
<td>Science and mathematics are taught partially together and partially as separate disciplines in the same classes.</td>
<td>One teacher (or a team of teachers) teaching a lesson (or lessons) in science and mathematics. Instruction involves evidence of a partial separation of the disciplines through a mini-science or mini-mathematics lesson.</td>
</tr>
<tr>
<td>Enhanced (EI)</td>
<td>Either science or mathematics is the major discipline of instruction, with the other discipline apparent throughout the instruction.</td>
<td>One teacher (or a team of teachers) teaching a lesson in science and mathematics. Learning objectives in one discipline dominate over the other discipline (and are more relevant for the grade level).</td>
</tr>
<tr>
<td>Total (TI)</td>
<td>Science and mathematics are taught in intended equality.</td>
<td>One teacher (or a team of teachers) teaching a lesson in science and mathematics, with the learning objectives intended and specified in each subject.</td>
</tr>
</tbody>
</table>

*Partial* integration was interpreted as an effort of a single teacher or a team of teachers to plan interdisciplinary lessons, but the actual implementation of the lesson(s) would not require a team of teachers and could be achieved by a single teacher. In other words, one teacher could teach mathematics and science partially together and partially
separately in a single lesson. This interpretation was supported by Ernest (1991), which Hurley classified as Partial integration. This study involved an interdisciplinary team teaching organization. Team teachers taught five periods each school day, and were scheduled for an individual and a team planning period.

Similar to Partial integration, Enhanced and Total integration types could be achieved by one teacher. A study by Dugger and Johnson (1992), classified by Hurley as Total integration, presented a program called Principles of Technology, which was designed to infuse general education mathematics and science concepts into the high school vocational curriculum. The characteristics of the infusion were only broadly explained in the article. The article did not describe a team effort involved in the actual implementation of the curriculum in the classroom. Similar studies in Hurley (2001) described curriculum materials written by and for teachers, but the presence of teams of teachers involved in the actual implementation of the programs was not specified (e.g., Austin, Hirstein, and Walen, 1997; Scarborough & White, 1994).

As stated earlier, Hurley’s descriptions did not reveal the exact meaning of Enhanced and Total integration. This may have been caused by the nature of the meta-analysis study by Hurley, which synthesized 31 studies into smaller categories. For example, it was unclear how Enhanced and Total integration differed from Partial integration. That is, whereas Partial integration appeared to imply that teachers could be presenting mathematics and science both separately and together in one class period, Enhanced and Total integration did not specify the extent of separating the two disciplines within a lesson. For example, it was unclear if mini-lessons in science or
mathematics could occur in \textit{Total} and \textit{Enhanced} integration. Given these restrictions, the researcher interpreted \textit{Enhanced} and \textit{Total} integration as types of integration with a large potential to be considered ‘seamless,’ with \textit{Total} integration lacking any evidence of intended separation of the subjects. In this form, mathematics and science objectives were treated as equally important.

\textit{Enhanced} integration was interpreted as being similar to \textit{Total} integration, but lacking the intent for mathematics and science to be taught with an equal instructional focus on learning objectives in both disciplines. This interpretation was supported by the work of Kolebas (1971), classified by Hurley as \textit{Enhanced} integration. This study focused on the effect of a program called ‘Science – a process approach’ on the intelligence, reading, mathematics, and interest in science levels of elementary school students. The program itself emphasized science processes and was thus categorized as \textit{Enhanced} integration due to the dominance of science over other subjects, including mathematics.

\textbf{Retrospective data analysis.} When the preliminary readings of the data were completed, the researcher began to examine codes and form categories emerging from the data set. The researcher also began to generate a list of leading themes. The researcher also continued to read through the data in search of new, unidentified categories. These categories were sought and coded based on the character of the recurring patterns within the data set (Guba & Lincoln, 1981). As a result, new themes were developed in light of the guidelines for effective evaluation of qualitative data described by Guba and Lincoln (1981) and Bogdan and Biklen (2007). The completeness of categories was reached when
only a minimum amount of data items remained unassigned, which included data that did not relate to the research questions.

Validity Issues

According to Gay, Mills, and Airasian (2009), some strategies that help to ensure validity of a qualitative study include prolonged participation at the study site, triangulation, use of peer debriefing, practice reflexivity, develop detailed descriptions of the context, collect documents, videotapes, audio recordings, artifacts, and other “raw” or “slice-of-life” data items, and conduct member checks (p. X). This study design satisfied these requirements in several ways. The school district had consistently nominated teachers for the program every year of the program’s operation between 2007 and 2013. Thus, the context of the school was familiar to the program personnel, including the researcher, as were the goals and objectives of the program to district’s teachers and school administrators. In addition, the program began to implement the co-teaching model in the early stages of its third year in this district (2009), based on the positive results gathered in support of the model during the first two years. This model was implemented in each subsequent year.

The researcher triangulated data for internal consistency by using several data sources to guide the analysis procedures (Denzin & Lincoln, 2000). These sources included field notes, memos, interview transcripts, teacher and student artifacts, and an attitudinal teacher survey. Further, two graduate students acted as “critical friends” during the course of the study, one during the data collection activities and one for the data analysis procedures. The researcher discussed the study with each individual.
student independently read and coded data. These codes were later compared with the
codes generated by the researcher.

The researcher remained cognizant of the need to be explicit about any events that
may affect the outcomes of the study. For this purpose, emerging thoughts about the
study were recorded in field notes and memos. The researcher provided a complete report
of everything that happened, including data collection efforts, missing and incomplete
data sources, and discrepancies in evidence emerging from data sources. It is nearly
impossible to record all observations while conducting research in a setting (Gay, Mills,
& Airasian, 2009), but all data sources were collected as soon as possible to “capture
accurately the essence of what took place” (p. 377).

**Ethics and Human Subjects Issues**

All study participants completed consent forms (teachers, Fellows, and parents of
the middle school students) and assent forms (students). Each teacher returned one signed
copy of the study consent form, and kept one copy for personal safekeeping. Through
consent and assent forms, teachers learned about the reasons why the study was being
done, what would happen to them while they were in the study, the timeline of the all
study activities, and about the expected benefits and risks of the study. In addition, these
forms also informed them that this program was publicized and that other people may
know that their district was a part of it.

The study participants were informed that contents of their individual
participation were confidential to the public and that they would not be linked to any
presentations or publications related to this study. For this purpose, pseudonyms were
developed and used instead of teachers’ real names. Each teacher was informed that he/she did not have to be in this study and that they could terminate their participation at any time. See Appendices F and G for teacher and parent consent forms, respectively, and Appendix H for the student assent form.
CHAPTER 4 – RESULTS

Introduction

This chapter addresses two research questions. For the first research question, the researcher describes the nature of mathematics and science connections made by middle school mathematics and science teachers in the GK-12 program, and the extent to which these connections represent mathematics and science integration. The second research question focuses on teachers’ perceptions and attitudes related to mathematics and science integration. The study of teachers’ perceptions and attitudes informed the researcher’s understanding of the nature of the connections made by teachers in the classroom.

The results for both research questions were based on the analysis of data gathered from classroom observations, teacher interviews, and an attitudinal survey, and included lesson-related artifacts. Artifacts collected in monthly professional development workshops informed the analysis of teachers’ perceptions of and attitudes about the integration of science and mathematics. The results are organized and presented based on the order of the research questions. For each research question, the results for mathematics teachers are presented first, followed by the results for science teachers.

Results for Research Question 1a

Research Question 1a: What is the nature of mathematics and science connections made by mathematics and science teachers in the GK-12 program?

In the first reading of the data (Phase 1), the researcher sought to understand the concepts that the teachers attempted to connect in the classroom. This reading was
guided by the integration approaches of content, process, and methodology proposed by Davison, Miller, and Metheny (1995). Evidence of connections of science content and mathematics content and connections of science processes and mathematics content are given below. This study also involved connections of teaching methodology in science and mathematics. Collectively, connections of content, process, and methods were studied based on data gather in field notes, memos, teacher interviews, and artifacts.

The researcher identified the lessons using teachers’ names (Molly, Maria, Stacy, and Steve) and numbers (1, 2, 3, 4) representing the order in which the lessons were observed for each teacher. Lessons taught by the mathematics teachers, Molly and Maria, were identified as: Molly1, Molly2, Molly3, and Molly4 (sixth grade), and Maria1, Maria2, Maria3, and Maria4 (seventh grade). In science, the Stacy1, Stacy2, Stacy3, and Stacy4 lessons were taught by Stacy, the sixth grade science teacher, and the Steve1, Steve2, Steve3, and Steve4 lessons were taught by Steve, the seventh grade science teacher. Lessons identified as Molly4 and Stacy4 represented one observation of a lesson co-taught by Molly and Stacy.

Connecting Science Content and Mathematics Content

The researcher found evidence of mathematics content and science content connections in seven lessons taught by mathematics teachers (Molly1-4, Maria1, 3) and all eight lessons taught by the science teachers. Tables 9 and 10 list the topics of content connections made by mathematics and science teachers, respectively.

Content connections by mathematics teachers. Molly and Maria, mathematics teachers, connected science content and mathematics content in seven lessons. Table 9
presents examples of mathematics content and science content in these lessons. The science content involved topics in life science (Molly1, Molly2, and Molly4) and earth science (Molly3) in sixth grade and life science in seventh grade.

The researcher examined lessons in Table 9 for their alignment with the school district curriculum and state content standards in mathematics and science. This practice was informed by the recommendations of Davison, Miller, and Metheny (1995), who suggested that “content specific integration involves choosing an existing curriculum objective from mathematics and one from science.” This objective implies that teachers “weave together the existing programs in science and mathematics.” (p. 227). Lonning and De Franco (1997) and Huntley (1997) made a similar argument about learning objectives in lessons identified as “balanced mathematics and science” and “mathematics and science,” respectively, calling them “appropriate for the grade level” (p. 212). Objectives aligned with the national (and state) standards, but not with the district curriculum, were referred to as “meaningful” (p. 212).

The researcher identified the lessons in Table 9 as being grade appropriate in mathematics and aligned with state content standards for mathematics (New Jersey Department of Education, 2008). In the Maria4 lesson, the teacher presented eighth grade material (e.g., line of best fit) to her seventh grade students at the end of the school year in mid-June. This material was found to be appropriate for the grade level by the teacher, who supported her lesson by saying, “This is actually an eighth grade standard, so I’m introducing them [students] to it now at the end of seventh grade, in an effort to prepare them, so they have some prior knowledge for next year.” Based on the teacher’s
decision to include this lesson in her seventh grade mathematics curriculum, the researcher also considered this lesson to be grade appropriate for the students.

Table 9

Science and Mathematics Content in Lessons Taught by Mathematics Teachers

<table>
<thead>
<tr>
<th>Lessons</th>
<th>Science content</th>
<th>Mathematics content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly1</td>
<td>Body systems (shapes of fingerprints)</td>
<td>Ratios, fractions, decimals, and percentages</td>
</tr>
<tr>
<td>Molly2</td>
<td>General structure and function of cells; Diversity</td>
<td>Numerical operations (multiplication); Measurement (length, area, units);</td>
</tr>
<tr>
<td>Molly3</td>
<td>Earth science (minerals and metals)</td>
<td>Profit, revenue, and cost)</td>
</tr>
<tr>
<td>Molly4</td>
<td>Spread and prevention of diseases; Vaccinations</td>
<td>Functions and relationships (increasing, decreasing, linear, slope); Modeling (scatter plots, changes over time)</td>
</tr>
<tr>
<td>Maria1</td>
<td>Environmental conservation and water usage</td>
<td>Data analysis; Mean; Volume</td>
</tr>
<tr>
<td>Maria3</td>
<td>Diversity (identification of trees, structure, age)</td>
<td>Numerical operations (multiplication with decimals); Solving equations (finding of the diameter given the circumference); Geometry (area formulas, circles); Measurement (circumference, units); Sampling</td>
</tr>
<tr>
<td>Maria 4</td>
<td>Diversity (population of species)</td>
<td>Equivalent ratios; Proportions; Estimation</td>
</tr>
</tbody>
</table>

Note. Content connections identified as “measurement” included activities in measuring.

In science content, six lessons (Molly1, Molly2, Molly4, Maria1, Maria3, and Maria4) were not classified as grade appropriate for science, but were related to state
content standards for life science in the middle grades (NJDOE, 2009). For instance, in seventh grade, physical science constitutes the majority of the district’s science curriculum, but Maria’s connections in the Maria1, Maria3, and Maria4 lessons were to life science instead. Similarly, the majority of Molly’s lessons (Molly1, Molly2, and Molly4) also focused on life science, and yet the sixth grade curriculum involved primarily earth science and physical science.

One lesson (Maria2) was not categorized as a content connection due to its lack of focus on science content. However, this lesson had the potential to connect mathematics content with grade appropriate topics in physical science, but these concepts were not examined in the lesson. Rather, the science in the lesson was designed as an experiment and conducted with a focus on mathematics content. The science concepts of forces, gravity, motion, or potential and kinetic energy, which were connected to this lesson, would have been grade appropriate had they been explored.

Interview data for the Maria2 lesson revealed that students initiated a brief discussion about the physics of bungee jumping in the lesson preceding the observation. However, Maria said that the discussion was primarily instigated and led by students and the extent of this discussion was limited by her lack of adequate content knowledge in physics. This is what Maria said in this context:

We did, before you got there, we talked about bungee jumping and what things would affect how far a person would jump if they did bungee jump, which did bring some physics into it, but I didn’t have the content to really elaborate on that. One kid brought up air resistance, several kids talked about height and weight,
and some even talked about the thickness and elasticity of the bungee cord itself.
So, we did talk about it a little bit, but I didn’t have the expertise to really go too far into that.

Despite physical science being an integral part of the seventh grade science curriculum in the district, Maria used the context of life science in three lessons. This could be explained by her perception of ‘connecting.’ In this study, Maria was asked to connect mathematics and science, and interview data showed that her interpretation of ‘connecting’ involved two disciplines, mathematics and science, supporting one another in a lesson. This perception was often illustrated by Maria as mathematics “used” as a tool to teach science or science “used” as a context to teach mathematics. As a teacher of mathematics, Maria prioritized the goals and objectives for mathematics and selected science concepts based on their appropriateness (and helpfulness) for mathematics learning, rather than their potential alignment with the school science curriculum. Maria’s focus was teaching mathematics rather than science.

Another reason that Maria’s content connections were more grade appropriate for mathematics than science may be related to her overall knowledge of the district science curriculum as well as her comfort level teaching physical science topics. In her post-study interview, she said, “I’m not familiar with the actual science standards for 7th grade,” and “I didn’t really give a lot of thought to that [science standards] to tell you the truth.” She also disagreed with the statement I am familiar with the content of the national and state science education standards on the pre- and post-study survey. In her pre-study interview, Maria stated that she connected mathematics with physics in the past “only
because science in the 7th grade according to the science curriculum is physical science. I haven’t pulled anything up because like I said I’m trying to keep with what the 7th grade should be doing. I believe 8th is life science, 6th grade is, I think, earth science.” She also said, “I don’t have a science background. I’m not a science person.” The researcher inferred that this teacher had some familiarity with the science curriculum, but did not perceive her role in the classroom as being that of a science teacher. Consequently, in her selection of lessons for this study, she focused on the curricular objectives in mathematics over science.

Familiarity with potential sources of lessons involving content connections was another possible factor in the lesson selection by both teachers--Maria and Molly. All eight lessons taught by these teachers were new lessons, and six of them were adapted from online sources. When asked to list conditions that would allow them to integrate mathematics and science in the future, both teachers listed “resources for integrated teaching” as one of the conditions. All eight lessons taught by these teachers were new lessons. Seven lessons were found and adapted using at least four online sources, and one lesson was adapted from Stacy’s resource published by the National Science Teacher Association. Maria adapted all of her lessons from two online sources. The teachers chose their final lessons based on a variety of reasons, most related to the teaching of mathematics. These reasons pertained to the Common Core standards (e.g., Maria2), the mathematics curriculum (e.g., Molly2), state testing (e.g., Molly3), and student interest in the topic (e.g., Molly1). For example, Molly selected the Molly1 lesson because “the science portion seemed fun to me, and I knew I could sneak in some math in there … I
just picked that science connection because I thought it seemed like fun for the kids. Like a break to them.”

Interview and survey data revealed that both teachers perceived their pre-study experiences with the integration of science and mathematics as limited. For example, in the context of the statement, *I teach lessons that integrate mathematics and science*, both teachers responded “disagree” on the pre-study survey. In contrast, both teachers responded “agree” to this statement on the post-study survey. Interview data indicated that Maria had some previous experience connecting science with mathematics, but she “never” tried teaching both science and mathematics together. In reference to her past experiences with science in her mathematics lessons, she discussed her past attempts to “pull in” science into mathematics (e.g., chemical equations), which she considered to be more interdisciplinary than integrated in nature. When asked if she included science in her mathematics lessons prior to the study, Molly responded, “No, no.”

Maria and Molly, lacked confidence in teaching physical science for the sixth and seventh grade curriculum and, therefore, taught lessons in earth and life sciences instead. For example, Molly said she was “least proficient in anything having to do with physics or chemistry.” However, in contrast to Maria, Molly was able to build upon her students’ prior knowledge of earth and life science, in addition to teaching new material in science. Most lessons, Maria’s and Molly’s, were not selected to complement the district’s science content curriculum for the grade level.

Although only one of Molly’s lessons was categorized as grade appropriate (Molly3), two lessons (Molly2 and Molly4) were strongly connected with the district
curriculum. The Molly2 lesson was appropriate for grade five, and the Molly4 lesson was aligned with the health education program for grade six. One possible explanation for this deliberate attempt to incorporate students’ previous knowledge of science was Molly’s ongoing collaboration with Stacy, a science teacher. Interview data regarding these two teachers revealed a frequent exchange of ideas about instruction, curriculum, and resources. These teachers were the only mathematics and science teachers in sixth grade, and they consulted each other about issues related to teaching, including lessons in this study. They also co-taught the Molly4/Stacy4 lesson. Similar collaborations were not observed between Maria and Steve at the seventh grade level, despite these teachers provided about the lack of collaboration two teachers sharing a common free period.

**Content connections by science teachers.** Table 10 presents connections of mathematics content and science content in lessons taught by science teachers. The sixth grade mathematics content focused on numerical operations (Stacy1), including decimals (Stacy1, Stacy2, and Stacy3), modeling (scatter plots, changes over time) (Stacy4), the general behavior of linear functions (Stacy4), and measurement and volume (Stacy3). In seventh grade, these topics included number sense (Steve1 and Steve3), numerical operations (Steve 1, Steve3 and Steve4), measurement (Steve 2 and Steve 4), including unit conversion (Steve2) and compound measurement units (Steve3), and data analysis (types of display: bar graphs, scatter plots, tables) (Steve2).

As shown in Table 10, both science teachers connected science content with the mathematics content of measurement, numerical operations, and modeling (scatter plots).
# Table 10

**Science and Mathematics Content in Lessons Taught by Science Teachers**

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Science content</th>
<th>Mathematics content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacy1</td>
<td>Tectonics; Rocks; Major geological events in history of the Earth</td>
<td>Number sense (large numbers, decimals); Numerical operations (division and subtraction of large numbers)</td>
</tr>
<tr>
<td>Stacy2</td>
<td>Gravity; Weight; Size and position of objects in the solar system</td>
<td>Number sense (fractions, decimals); Numerical operations (multiplication with decimals)</td>
</tr>
<tr>
<td>Stacy3</td>
<td>Sinking and floating (density, weight, mass, buoyancy); Liquid (water) displacement and volume</td>
<td>Numerical operations (subtraction of decimals); Measurement (weight and volume, units)</td>
</tr>
<tr>
<td>Stacy4</td>
<td>Spread and prevention of diseases; Vaccinations</td>
<td>Functions and relationships (increasing, decreasing, linear, slope); Modeling (scatter plots, changes over time)</td>
</tr>
<tr>
<td>Steve1</td>
<td>Ionic compounds (balance of positive and negative charges)</td>
<td>Number sense (least common multiples); Numerical operations (addition and multiplication of positive and negative numbers)</td>
</tr>
<tr>
<td>Steve2</td>
<td>Chemical reactions</td>
<td>Measurement (length, units); Unit conversion; Compound measurement units; Data analysis (type of display)</td>
</tr>
<tr>
<td>Steve3</td>
<td>Kinetic energy (speed and mass)</td>
<td>Number sense (whole numbers with exponents); Compound measurement units; Numerical operations (multiplication, including whole numbers with exponents);</td>
</tr>
<tr>
<td>Steve4</td>
<td>Potential and kinetic energy; Energy transfer</td>
<td>Numerical operations (multiplication and division, including whole numbers with exponents); Measurement (time, length, units)</td>
</tr>
</tbody>
</table>

*Note. Content connections identified as “measurement” included activities in measuring.*
Numerical operations with decimals were most common in the sixth grade. In the seventh grade, measurement and numerical operations were most common.

Seven lessons taught by science teachers involved grade appropriate mathematics and science content, aligned with the district science curriculum and state curriculum content standards (NJDOE, 2008). The science content in the Stacy4 lesson was a component of the district’s health education program, rather than the science curriculum for sixth grade. These eight lessons frequently solicited students’ prior knowledge of mathematics content. Teachers were able to use mathematics to teach science with minimal instructional time being devoted to the teaching (introduction) of the mathematical content involved in the lessons. The mathematical activities were primarily procedural. Three lessons (Stacy1, Stacy2, and Steve3) involved non-procedural activities (e.g., reasoning about large numbers, decimals, and fractions). Both teachers incorporated their knowledge of students’ mathematical backgrounds in the lessons.

An example of a lesson that incorporated students’ background knowledge in mathematics is the Steve1 lesson. In this lesson on ionic compounds, numerical operations involving the addition and multiplication of positive and negative numbers were used to balance chemical compounds. Numerical operations with negative numbers had previously been introduced to students in the mathematics classroom. Steve stated the following about the role of his students’ mathematics content knowledge in the lesson:

I think it does help that they’re doing negatives and positives, which is the core of the math, of the arithmetic, for this lesson, in math class as well, or have done it
recently … the kids had reasonable understanding already of just the basic mathematics, and it was just applying what they originally knew about, say, negatives and positives and applying it to a scientific avenue, I suppose.

Analogous to Steven, Stacy’s lessons involved grade appropriate mathematics content. For instance, in one lesson (Stacy2), students calculated their weight on other planets by multiplying their weight (on Earth) by appropriate scale factors in a decimal form (gravitational attraction) (e.g., 0.4 for Mercury, 0.9 for Venus). In addition, students listed the planet’s gravitational attraction from least to greatest. This lesson did not introduce students to decimal multiplication or decimal comparison, but rather utilized and reinforced their skills with these concepts.

The attention to decimals in three of the four lessons presented by Stacy could also be explained by her ongoing collaboration with Molly, both before and during the study. Data collected from interviews revealed that Stacy remained aware of Molly’s curriculum, including decimals. In her lessons, she consciously reinforced mathematical skills taught previously in Molly’s classroom. These efforts resulted in activities that complemented and supported students’ learning of mathematics.

**Summary.** Mathematics and science teachers invited the researcher to view lessons that teachers selected as representing connections between mathematics and science. Consequently, at each visit, the researcher was more interested in learning about the types of connections that were made in the classroom rather than the fact that teachers made connections. As shown in Tables 9 and 10, evidence of deliberate content
connections was found in all but one lesson (Maria3). These fourteen lessons connected content in both mathematics and science.

Grade appropriate connections were more common in lessons taught by science teachers than lessons taught by mathematics teachers. Consequently, content connections in science classrooms were more deliberate. The researcher inferred that science teachers were more cognizant of and dependent more upon their students’ knowledge of content in mathematics than mathematics teachers were on their students’ background knowledge of science content. Based on the data in this study, it is plausible that science teachers made deliberate attempts to utilize their students’ background knowledge of mathematics in their teaching. On the other hand, mathematics teachers presented new concepts in science as part of six lessons, without a clear indication in the interviews or classroom observations that these concepts were previously studied by students in science classrooms.

**Connecting Science Processes and Mathematics Content**

In addition to content connections, the researcher identified evidence of lessons which connected science processes and mathematics content. Davison, Miller, and Metheny (1995) suggest that the integration of mathematics and science can be achieved “through the use of real-life activities in the classroom” (p. 228). By presenting students with opportunities to predict, infer, classify, hypothesize, observe, collect data, analyze the data, and make and report conclusions, communicate, teachers can enable students to experience science processes and to perform the needed mathematics (p. 228).
The evidence of science processes was identified in seven lessons taught by mathematics teachers (Molly1, 2, 4, and Maria1-4) and five lessons taught by science teachers (Stacy3, Stacy3, Stacy4, Steve2, and Steve4). The evidence of science processes included cases of classroom experiments and demonstrations involving characteristics described in the previous paragraph. Data regarding connections of science processes with mathematics content were gathered during classroom observations and interviews. For example, when asked to specify learning objectives in science in the debriefing interviews, some teachers listed science processes as examples of such objectives.

The aforementioned science processes (Davison, Miller, and Metheny, 1995, p. 228) are related to mathematics standards for data analysis proposed by the *New Jersey Core Curriculum Content Standards for Mathematics* (NJDOE, 2008), mathematical processes of the *Principles and Standards for School Mathematics* (NCTM, 2000), and mathematical practices proposed by the *Common Core State Standards for Mathematics* (CCSSI, 2010). For instance, at the time of the study, content standards for data analysis in mathematics for sixth and seventh grade included collection, organization, and presentation of data. Thus, the distinction of these processes as scientific, rather than scientific and/or mathematical, was based on the theoretical framework of the study, in agreement with the description of “process integration” presented by Davison, Miller, and Metheny (1995).

**Science process connections by mathematics teachers.** As shown in Table 11, evidence of science processes and mathematics content connections was found in seven lessons taught by mathematics teachers. Three lessons were observed in sixth grade
(Molly1, Molly2, and Molly4) and four in seventh grade (Maria1, 2, 3, and 4). The science process connections involved hypothesizing (Molly2 and Molly4), data collecting (all lessons), and organizing data into tables (Molly1, Molly4, Maria1, 2, 3, and 4), lists (Molly1), and graphs (Molly4, Maria2). These seven lessons had specific learning objectives for mathematics, and the science processes were used to enhance student experiences with mathematics learning. With the data collected directly in the observed lesson, or sometimes prior to the observation (Maria1), students generated conclusions about appropriate mathematical concepts or ideas in the lesson, and shared their findings with each other. In one lesson (Molly2), students prepared posters with their data results.

The lesson’s data collection activities involved measurements in simulated and real conditions. In four lessons (Molly2, Molly4, Maria2, and Maria4), students engaged in simulations of real-life phenomena or activities. For example, in the Maria4 lesson, students used beans as birds (red robins) and estimated the size of the red robin population in the forest. In the Molly4 lesson, students tagged each other, simulating the spread of a disease. Real objects were examined in three lessons (Molly1, Maria1, and Maria3). These objects included fingerprints (Molly1), household water usage (Maria1), and the circumference of trees (Molly3).

Maria incorporated data collection and analysis in all of her lessons, including two lessons that involved non-simulations. The connections of scientific processes with mathematics connect were intentional and related to the Common Core State Standards for Mathematics (CCSSI, 2010) for grades 6-8. Interview data revealed that Maria utilized the opportunity to connect science with mathematics to test new lessons that
would be later appropriate for teaching in subsequent years in alignment with the new
*Common Core* standards. When asked in the post-study interview about the reason for
choosing her lessons for observation, she said, “First, with [the state] switching over to
the *Common Core Standards* next year, that was in my head. I was trying to kill a lot of
birds with one stone. Um, I wanted hands-on lessons that students would, they would be
discovery-based.” For this teacher, the activities involving data collection and
observation (science processes) met this goal.

Both mathematics teachers agreed that scientific activities improved the
authenticity of the learning contexts and made mathematical activities more interesting
for students. For example, Maria used science processes with the goal of improving her
students’ motivation to learn. She explained:

I wanted the data to be genuine. I wanted them [students] to collect their own
data, not me handing them a bunch of numbers, um, which alone to me is a
scientific process, collecting the data and making their observations. That alone is
science … And I do think with real life data, the kids make the connections
better than me handing them a table and saying, “Okay, here is the 1990 Census
results.” They couldn’t care less about that. To them, it is just a number, and I
lose them. This is real. This is connections.

Similarly, Molly frequently described science as “fun” and “interesting,” not only for the
students but also for herself. She said the following about the role of science in the
Molly1 lesson, “The science was to make it interesting and fun.”
When asked about the role of science or about the science learning objectives in her lessons in post-observation debriefing interviews, Maria named science processes in the context of all four lessons. However, there is weaker evidence of a direct focus and acknowledgement of data collection and analysis by Molly, despite evidence of process connections gathered as part of observations. These differences among teachers may be related to their educational backgrounds, personal teaching styles and experiences, past professional development activities, and curricular needs. As stated earlier, one of Maria’s goals for this study was to find hands-on, discovery-based lessons that she could also use in the future. This goal was reflected in her lesson objectives. The data does not reveal evidence of a similar goal or focus for Molly.

Maria implemented data collection and analysis in four lessons. Perhaps coincidentally, data analysis was also a component of the seventh grade mathematics curriculum. Interview data revealed that activities in data collection and analysis were perceived as just as much scientific as mathematical for this teacher. For instance, in the Maria1 lesson, Maria described the learning objectives in mathematics using science processes by saying, “My learning objectives in math, I’m actually strict with math objectives, my objective is to be able to get them to collect their data, and then analyze the data using the mean.” In the same lesson, science was not described as a process but rather as “the water usage” and “the environment.” However, in her post-study interview, she said, “I wanted them [students] to collect their own data, not me handing them a bunch of numbers, which alone to me is a scientific process, collecting the data and
making their observations.” The researcher inferred that this teacher viewed scientific processes as components of both science and mathematics.

Table 11

*Connections of Science Processes and Mathematics Content by Mathematics Teachers*

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Science processes</th>
<th>Mathematics content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly1</td>
<td>Data collection, classification, analysis, and conclusions</td>
<td>Ratios, fractions, decimals, and percentages</td>
</tr>
<tr>
<td>Molly2</td>
<td>Hypothesis, data collection, data analysis, conclusions, data presentation</td>
<td>Numerical operations (multiplication); Measurement (length, area, units);</td>
</tr>
<tr>
<td>Molly4</td>
<td>Prediction, data collection, analysis, and conclusions</td>
<td>Functions and relationships (increasing, decreasing, linear, slope, exponential); Modeling (scatter plots, changes over time);</td>
</tr>
<tr>
<td>Maria1</td>
<td>Hypothesis, data collection, analysis, and conclusions</td>
<td>Data analysis; Mean; Volume</td>
</tr>
<tr>
<td>Maria2</td>
<td>Data collection, analysis, prediction, and conclusions; Problem solving</td>
<td>Modeling (scatter plots); Functions and Relationships (equations with two variables, including line of best fit, slope, y-intercepts)</td>
</tr>
<tr>
<td>Maria3</td>
<td>Data collection, analysis, and conclusions</td>
<td>Numerical operations (multiplication with decimals); Solving of equations (finding of the diameter given the circumference); Geometry (area formulas, circles); Measurement (circumference, units); Sampling</td>
</tr>
<tr>
<td>Maria4</td>
<td>Data collection, analysis, and conclusions</td>
<td>Equivalent ratios; Proportions; Estimation</td>
</tr>
</tbody>
</table>
One lesson not included in Table 11, the Molly3 lesson, involved calculations of the profit, cost, and revenue made by a mine owner. In this lesson, students were engaged in a hands-on activity, but the activity was not conceived as an experiment. Specifically, students “mined” chocolate chips from a cookie and used chocolate chips as natural resources for sale. This lesson was previously identified as a content connection.

Table 12

*Connections of Science Processes and Mathematics Content by Science Teachers*

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Science processes</th>
<th>Mathematics content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacy2</td>
<td>Data collection, analysis, and conclusions, discussion of results</td>
<td>Number sense (fractions, decimals); Numerical operations (multiplication with decimals)</td>
</tr>
<tr>
<td>Stacy3</td>
<td>Data collection, analysis, and conclusions</td>
<td>Numerical operations (subtraction of decimals); Measurement (weight and volume, units)</td>
</tr>
<tr>
<td>Stacy4</td>
<td>Prediction, data collection, analysis, and conclusions</td>
<td>Functions and relationships (increasing, decreasing, linear, slope, exponential); Modeling (scatter plots, changes over time)</td>
</tr>
<tr>
<td>Steve2</td>
<td>Hypothesis, identifying and controlling variables, data collection, data analysis, conclusions, and presentation of results</td>
<td>Measurement (length, units); Unit conversion; Compound measurement units; Data analysis (type of display)</td>
</tr>
<tr>
<td>Steve4</td>
<td>Data collection, analysis, and conclusions; Problem solving</td>
<td>Numerical operations (multiplication and division, including whole numbers with exponents); Measurement (time, length, units)</td>
</tr>
</tbody>
</table>

*Science process connections by science teachers.* Table 12 presents lessons taught by science teachers that involved science processes, together with topics in
mathematics content. Collectively, science teachers presented five lessons with evidence of science processes (Stacy2, 3, and 4, Steve2 and 4). The remaining lessons (Stacy1, Steve1, and Steve3) involved science content and mathematics content connections without scientific processes.

As stated above, science teachers connected scientific processes with mathematics content in five lessons (Stacy2, Stacy3, Stacy4, Steve2, and Steve4). Observed lessons involved classroom experiments, and included student activities in collection, analysis, and interpretation of data. Students were asked to make conclusions based on their own observations and to share the results with the rest of the class. In the Steve4 lesson, they presented their data via posters. The Stacy2 lesson was the only lesson in which students generated data in the classroom without performing an experiment or a simulation. In this lesson, they calculated their weights on different planets in the Solar System and then used their data to make inferences about the sizes of the planets, gravity, and distances between planets.

Three lessons (Stacy3, Steve2, and Steve4) involved experiments, and one lesson was a simulation of the spread of disease (Stacy4). In the Stacy3 lesson, students engaged in a class experiment. The execution of activities in this experiment involved a whole-class set up due to the lack of equipment needed for small groups. A similar approach was also observed in the Stacy4 lesson, which required a whole-class setting to conduct the data collection part of the lesson. In contrast, the experimental procedures in the Steve2 and Steve4 lessons were conducted almost exclusively by groups of 3-4 students.
In these two lessons, students adhered to laboratory worksheets in a discovery of new ideas about scientific concepts of chemical reactions and energy transfer, respectively.

One explanation for the differences in the activities conducted by Stacy and Steve could be both the frequency and content of their past experiences with lessons involving classroom-based experiments, largely due to the limited access to appropriate equipment in Stacy’s classroom. For example, in response to a question about something she would like to improve in her teaching, Stacy said, “Oh, sure, just my overall knowledge of some science. I would like to be able to do more hands-on experiments/activities with them because I really think it’s just so much more interesting that way and that they’ll learn better (...) And I don’t do that here. I try to do that here but I am limited.” In addition, these two teachers aligned their lessons with the district curriculum. In sixth grade, the curriculum involved topics in earth and physical science. In seventh grade, science topics were primarily related to physical sciences (chemistry and physics), which made the use of experiments a bit easier to incorporate into the lessons.

**Summary.** Although process connections identified in Tables 11 and 12 were common, these connections were not identified in all fifteen lessons. Lessons that lacked evidence of classroom experiments were excluded from these tables. As shown in Tables 11 and 12, more process connections were made by mathematics teachers than science teachers. In lessons that were taught by science teachers, which did not involve experiments, teachers engaged students in activities focusing on problem solving (Stacy1) and thinking with mathematics (Stacy1, Steve1, and Steve3).
In mathematics classrooms, process connections were utilized intentionally to enhance student learning experiences with mathematics through activities that allowed them to collect their own data, think about and make representations of the data (e.g., scatter plots, tables, lists), and generate conclusions based on the analysis of the data. Both mathematics teachers perceived scientific processes as appropriate for mathematics teaching and learning. The activities involved in classroom experiments were perceived as positive in relation to raising student engagement in mathematics learning and making learning more authentic for students.

In science classrooms, science processes were connected to mathematics content; however, these processes sometimes were used to teach new topics in science rather than mathematics. In two lessons, Steve2 and Steve4, students were given an opportunity to engage in science processes to learn new concepts in science. With regard to integration of science processes and content in mathematics, mathematical skills and procedures were necessary for the execution of experiments, but there was a weak focus on the actual learning of mathematics content in these lessons. Students learned about applications of mathematics in science, but these lessons were not focused on the development of new content knowledge in mathematics.

**Connections Involving Science Teaching Methodology**

Davison, Miller, and Metheny (1995) suggest methodological integration in which “good” science methodology is integrated into “good” mathematics teaching (p. 228). In this approach to integration, teachers integrate “good” science methodology to teach mathematics by enabling students to engage in explorations grounded in students’
previous knowledge, develop conceptual understandings of material, and expand newly generated ideas to other contexts. Students investigate new material using inquiry and discovery.

Evidence of mathematics teachers integrating “good” science methodology to teach mathematics was common in the observed lessons. As shown in Table 11, seven lessons connected science processes with mathematics content. In these lessons, students made predictions of future outcomes in mathematics and/or science contexts, collected data, made observations, generated conclusions, and shared results. With their focus on learning through exploration, conceptual invention, and expansion of the idea (Davison, Miller, and Metheny, 1995, p. 229), these activities represented “good” science methodology. For example, in the Molly2 lesson, students used manipulatives (pipe cleaners) to investigate (maximize) areas of polygons (cells) with a constant perimeter (cell membrane). Students did not conduct experiments in this lesson, but rather engaged in scientific inquiry and discovery. In the Molly3 lesson, not listed in Table 11, students investigated profit, cost, and revenue in a hands-on, small-group activity.

As shown in Table 10, science teachers incorporated mathematics and science content into every lesson, and five lessons involved process connections (see Table 12). The lessons involving process connections built upon the students’ previous knowledge of mathematics. However, while science was the focus of instruction in all of the lessons taught by the science teachers, the focus on mathematics teaching was observed in only three lessons (Stacy1, 3, 4). In these lessons, students reasoned with and about decimals (Stacy1), found the volume of irregularly shaped objects (Stacy3), and investigated the
properties of a scatter plot (Stacy4). For examples, in the Stacy1 lesson, students located decimals on a roll of bathroom tissue paper. The roll represented the timeline of the Earth’s geological history. The researcher inferred that science teaching methodology was applied in the teaching of mathematics in these three lessons.

In the lessons observed in this study, the researcher found it difficult to differentiate “good” science teaching and “good” mathematics teaching, since teachers in both disciplines supported inquiry and discovery in the classroom. For instance, good mathematics and science teachers enable students to build upon their prior knowledge. Both disciplines value hands-on learning. In mathematics classrooms, teachers incorporate manipulatives to enable students to develop deeper conceptual knowledge of mathematics, prior to the development of procedural knowledge (e.g., NCTM, 2000). In science, students conduct experiments to test hypotheses. Collectively, the activities described above represent “good” science teaching methods and “good” mathematics teaching methods, and demonstrate what these methods have in common, despite the differences in the experimental nature of science and deductive nature of mathematics.

**Results for Research Question 1b**

*Research Question 1b: What is the extent to which teacher practices of mathematics and science connections represented mathematics and science integration?*

To answer this research question, the researcher sought to understand the extent to which the lessons integrated mathematics and science. Upon the completion of Phase 1, two new readings of the data were conducted (Phase 2 and Phase 3) to examine the depth of mathematics and science connections. The goal of the reading in Phase 2 was to learn
about grade appropriateness of the learning objectives in each lesson. Thus, the alignment Phase 3 focused on the arrangement of mathematics and science concepts that was used to reach each of the objectives. The analysis of Phase 2 is presented first, followed by Phase 3.

**The Analysis of Phase 2 (Continuum Model)**

Findings from the Phase 2 analysis, presented below, relate the extent of integration occurring in the lesson observations, post-lesson interviews, and surveys. These findings were related to the *continuum models for integration* discussed by Lonning and De Franco (1997) and Huntley (1999). In this reading, the researcher analyzed the roles played by mathematics and science in each lesson. The middle of the continuum represented activities that “balanced mathematics and science” (Lonning & De Franco, 1997). Some “balanced” activities were then identified as “mathematics and science” (Hurley, 1999).

The extent of integration by mathematics teachers is presented first, followed by the extent of integration by science teachers. In each case, the lessons are grouped and presented in accordance with their location along the continuum. Lessons are grouped into the following categories: Mathematics focus (mathematics with science), Balanced mathematics and science, Mathematics and science, and Science focus (science with mathematics).

**Extent of integration by mathematics teachers.** Mathematics teachers connected mathematics content and science content in seven lessons (Molly1, Molly2, Molly3, Molly4, Maria1, Maria3, and Maria4). In these lessons, instructional time was
devoted to the presentation of science topics with scientific videos (Molly3 and Maria4), diagrams (Molly2 and Maria3), online resources (Molly3, Maria1, Maria3, and Maria4), manipulatives (Molly2, Maria2, and Maria4), models (Molly1, Molly3, Maria3), and other instructional tools (Molly1). In mathematics, learning objectives involved new and past topics and were grade appropriate for the district’s and state’s mathematics curriculum.

**Mathematics focus (mathematics with science).** The Molly1, Molly2, Molly4, Maria1, Maria3, and Maria4 lessons were classified as “mathematics focus” or “mathematics with science,” due to their lack of alignment with the school district science curriculum. The Molly1, Maria1, Maria3, and Maria4 lessons were aligned with the state science content curriculum for grades 6-8 (NJDOE, 2009), and, with this new condition, could be reclassified as “balanced” (Maria3 and Maria4) and “science focus” (Molly1).

In the Maria1 lesson, students calculated the average daily amount of water used per person in their household using data they collected at home over the course of one week. This lesson was part of a larger project, which enabled students to share their findings with students around the country and the world. The observed lesson involved calculations of averages, reasoning about volume, and comparison of results among students. The activities observed in this lesson were identified as “mathematics focus” or “mathematics with science,” with the science functioning as a context for mathematics teaching. However, the overall project, which involved several weeks to complete, was “balanced mathematics and science,” because it provided students with opportunities to
extend their knowledge of both science (environmental conservation) and mathematics (mean). This conclusion was drawn based on the examination of the project overview provided by the teacher.

In the Maria2 lesson, the researcher found limited evidence of focus on the teaching of science content. In this lesson, students predicted how many rubber bands were needed for an object to safely jump from a given distance. The lesson provided students with opportunities to explore linear relationships in the context of physics by collecting data, constructing a scatter plot, and generating a line of best fit. In the context of the continuum of integration, this lesson reflected characteristics of “mathematics focus” (Lonning and De Franco, 1997) or “mathematics with science” (Huntley, 1999). The science content of this lesson constituted part of the context, but the lesson did not make explicit connections between mathematics and science content.

**Balanced mathematics and science.** As the only grade appropriate lesson taught by mathematics teachers, the Molly3 lesson could have been qualified as “balanced;” however, this lesson was “mathematics with science” due to the predominance of mathematics content over science in lesson activities. On the day of the observation, students pretended to be mine owners, calculated profit, cost, and revenue obtained from the sale of chocolate chips “mined” from cookies, and discussed their results in small groups. The development of mathematical skills dominated in this lesson, and science acted in support of mathematics learning.

However, the Molly3 lesson was a two-day lesson, with the observed class period being on Day 2. Although the researcher did observe the first day of this lesson,
interview data showed evidence of science content exploration on Day 1. According to the teacher, students watched a video about natural resources, a sixth grade science topic studied with Stacy earlier in the year. They also completed science-related activities using online resources. This lesson (Day 1) was dominated by science content with only a limited focus on mathematics. Based on Molly’s instructional goals for Day 1 and Day 2, the researcher reclassified this two-day unit as “balanced mathematics and science,” because it involved grade appropriate objectives in mathematics and science, and overall, discipline predominated in this unit.

Because the lessons were not components of the district’s science curriculum, the Molly2, Molly4, Maria3, and Maria4 lessons, could only initially be classified as having a “mathematics focus.” The science content in the Molly4 lesson was grade-level appropriate in health education. In the Molly2 lesson, the content of cellular structure was aligned with the fifth grade curriculum. In the Maria3 and Maria4 lessons, science content was related to the state standards for science in grades 6-8 and the eighth grade life science curriculum in the district. However, these lessons could be classified as “balanced mathematics and science,” only if the state science standards for grades 6-8 were considered to be appropriate.

**Mathematics and science.** In at least three lessons taught by mathematics teachers (Molly2, Molly4, and Maria3), teachers attempted to make explicit mathematics and science connections (Huntley, 1999). These connections included the following concepts in science and mathematics: 1) the shape of a cell and the area of polygons with equal perimeter; 2) the age of a tree and the length of its circumference, and 3) the rate of
disease spread and the shape of a scatter plot. These connections failed to align with the
district science content curriculum. Aligned with the state standards, these lessons could
potentially be considered to be “mathematics and science” (Huntley, 1999).

The condition of content being appropriate for the given grade level in both
mathematics and science in balanced (and integrated) lessons was a decisive factor in
lesson placement along the continuum. Under this condition, only two lessons in the
entire study qualified as “mathematics and science,” the Stacy1 and Stacy3 lessons.
Based on Huntley (1998, 1999), these lessons were both integrated. They aligned with
the district curriculum for mathematics and science, and involved learning objectives in
both disciplines.

**Science focus (science with mathematics).** As stated earlier, scientific concepts
were of primary importance in lessons identified as “science focus” or “science with
mathematics.” In the set of lessons taught by mathematics teachers, the Molly1 lesson
aligned with the district mathematics curriculum, but not with the science curriculum for
sixth grade. The primary reason why this lesson was selected for the study was not its
relevance to the mathematics curriculum but rather its science content, which appeared
interesting to the teacher. She said, "I just picked it because I thought it just seemed fun,
like the whole fingerprinting, the science portion seemed fun to me, and I knew I could
sneak in some math in there, (...) but I just picked that science connection because I
thought it seemed like fun for the kids. Like a break to them."

Despite the mathematics connection in this lesson, most of the instructional time
in the Molly1 lesson was devoted to introducing the new science concept of fingerprints
(shape of papillary lines). In small groups, students used magnifying glasses to examine the shapes of their own papillary lines, and classified these shapes into categories (loops, arches, whorls, or other). Toward the end of the period, students also calculated the percent of each shape in the class data set and compared their results to the national average.

The Molly1 lesson would have been classified as “balanced” if it had focused on the development of the understanding of fractions, decimals, and percentages. Instead, students converted fractions to decimals using calculators (not a new topic), and applied a procedure (new concept presented by the teacher) to convert decimals to percentages. In science, an explicit connection of papillary lines to life science (e.g., body systems) would have made the lesson more meaningful in terms of its relevance to the sixth grade science curriculum.

**Extent of integration by science teachers.** Guided by Lonning and De Franco (1997), the researcher used data from classroom observations, interviews, and artifacts as sources of information regarding the alignment of each lesson with the district curricular standards. With the exception of the Stacy4 lesson, lessons taught by science teachers aligned with the school district mathematics and science curricula as well as state content standards for mathematics (NJDOE, 2008) and science (NJDOE, 2009). The Stacy4 lesson aligned with the district’s health education curriculum, but not with the science curriculum for sixth grade. These findings are significant for the subsequent presentation of the data results related to the continuum model of integration.
Science focus (science with mathematics). Lessons identified as “science focus” or “science with mathematics” involved grade appropriate learning objectives in science. These lessons were also grade appropriate in mathematics. However, science was identified as predominate over mathematics, with the learning objectives in mathematics either missing or unclear. Teachers taught new material in science using mathematics, and limited instructional time was devoted to the development of deep content knowledge in mathematics. Mathematics and science were not found to be equally dominant, with science taking the lead, in the Stacy2, Steve1, Steve2, Steve3, and Steve4 lessons. In these lessons, teachers taught new material in science, and the focus of instruction was the development of deeper scientific knowledge. Mathematical skills were utilized in these lessons, but were not the focus of instruction. For example, in the Steve1 lesson, students found least common multiples and multiplied positive and negative numbers to balance ionic compounds (new science topic). In the Stacy2 lesson, students multiplied decimals (without calculators) to compute their own weight on each planet in the Solar System (new science concept) and to discuss the concept of gravity. In the Steve2 lesson, students constructed bar graphs to represent data collected in a class experiment (new science concept).

Because mathematics and science in the lessons described in the previous paragraph were both included components of the district curriculum, these lessons were initially considered to be “balanced.” However, the researcher later classified them as having a “science focus” due to the conditions explained in the previous paragraph. When asked about the role of mathematics in the science classroom, both teachers’ responses
focused on the application of procedural knowledge in science contexts, rather than the development of a conceptual understanding of these procedures.

**Balanced mathematics and science.** Lessons identified as “balanced” involved grade appropriate content in mathematics and science and were identified as lessons in the middle of the continuum model for integration of mathematics and science. In these lessons, learning objectives were identified and/or observed in each discipline, and neither discipline was perceived as being dominant in the lesson.

Two lessons (Stacy1 and Stacy3) satisfied the conditions for “balanced mathematics and science,” and were placed in the middle of the continuum. In the Stacy1 lesson, students reasoned about large numbers and decimals (mathematics content) in the context of the Earth’s geological history (science content). In the Stacy 3 lesson, students measured volume of irregular shapes and explored the buoyancy of floating and sinking objects. These two lessons involved the learning of new material in both disciplines. In contrast, in the Stacy2 lesson, students applied their prior knowledge of multiplication with decimals and the ordering of decimals in a lesson on gravity.

In the Stacy4 lesson, new material in both science and mathematics was presented; however, the lesson was only aligned with the district’s mathematics content standards, and not the science. As such, the Stacy4 lesson was a classified as a lesson with “mathematics focus,” because students learned grade appropriate topics in mathematics, not science. However, the content of this lesson was related to state standards for life science in grades 6-8, and this lesson was aligned with the district
curriculum in health education. In this new context, under new conditions, the lesson portrayed in the Stacy4 lesson was “balanced mathematics and science.”

Mathematics and science. Huntley (1998) suggests that integrated lessons make explicit connections between the disciplines during instruction (p. 321), and some of the balanced lessons in this study (including lessons that were not aligned with the district curriculum) provided evidence of such connections. A related illustration of this connection in Huntley involved a lesson on photosynthesis and the surface area of leaves in the rainforest. In this lesson, students extend their knowledge of fractions to a new concept (the area of an irregularly shaped object) and learn about the process of photosynthesis. They also learn about the relationship between leaf size and the rate of photosynthesis in the plant. This latter component of the lesson exhibits an explicit connection between mathematics and science.

The Stacy1, Stacy3, and Stacy4 lessons were considered “balanced” (Stacy 4 when state standards were considered), and involved explicit connections between mathematics and science. These connections included: the magnitude of large numbers and the relative distance between geological events in the Earth’s history (Stacy1), the amount of water (volume) displaced by a floating/sinking object and the weight of the object (Stacy3), and the shape of a scatter plot and the rate of disease spread (Stacy4).

As noted above, three lessons taught by Stacy (Stacy1, Stacy3, and Stacy4) involved learning objectives in mathematics and science. Stacy’s focus on mathematics and science learning in these lessons can be explained by the nature of her professional
collaborations with Molly during this study. Interview data revealed evidence of efforts by these two teachers to collaborate. Stacy said:

But I enjoyed working with her [Molly]. Didn’t realize until this year how much I didn’t work with her on subjects, and then this being integrating math and science even when the fellows weren’t here, me trying to integrate more math, and I would say to her, ‘You know, I’m going to do this,’ and she would say, ‘You know, they struggle with this,’ or ‘Hit this point more than this point,’ and so, I guess in this year, it was great working with her but it also showed me how much I didn’t work with her prior. So I hope we can continue, somehow.

Consequently, Stacy’s lessons focused on the development of a stronger knowledge base in mathematics, particularly in the area of decimals, and this focus was related to her work and discussions with Molly. Her lessons included reasoning about decimals (Stacy1), comparing decimals (Stacy2), and multiplication of decimals (Stacy2, 3). In the context of decimals in the Stacy1 lesson, Stacy said:

And then … she [Molly] has a hard time with them with the decimals. So when we got to the point when it was the 3.25 and it was just the, you know, .1, for them to figure out on that one square of bathroom tissue where are they going to put that out. I guess that was good skills with the decimals also. And I did have to ask Molly about that yesterday.

In contrast to Stacy and Molly, collaborative efforts were not typically noted in seventh grade. These teachers were supportive of one another, but their collaborative efforts were not as extensive as those observed for the sixth grade team. This weaker
collaboration in seventh grade was shown in a statement by Steve, “I’m not really sure what they do in the math classrooms here.” Maria’s post-study interview revealed that her collaboration with Steve intensified in the last two months of the study.

Three lessons taught by Stacy were found and adapted for the purpose of this study (Stacy1, 3, 4). Stacy was teaching these lessons for the first time. The sources of these lessons included online websites as well as other resources for mathematics and science integration. In contrast, Steve used his own lessons for all four observations, and his lessons were found to be more science focused than Stacy’s. This result may indicate the need for continued professional development in future efforts to integrate mathematics and science in the classroom.

**Summary.** As shown in Table 13, based on the alignment of each lesson with the middle school state standards in mathematics and science, three lessons taught by mathematics teachers were classified as “mathematics focus,” four as “balanced,” and one lesson as “science focus.” Science teachers taught five “science focus” lessons and three “balanced” lessons. When the district curriculum for the given grade level was considered, only two lessons in the whole study qualified as balanced, and all lessons taught by mathematics teachers were classified as having a mathematics focus. Since grade appropriateness of content in the lesson may vary among districts, this condition plays an essential role in how lessons are classified along the continuum in each district.

This result highlights the need for teachers of science and mathematics to consider grade appropriate content when connecting mathematics and science. By making lesson objectives more relevant to the district curricula in each subject, integrated practices can
enable teachers to focus instruction on learning objectives that are common to science and mathematics. However, the implementation of science concepts not included in the district curriculum could also enhance student experiences with science by introducing them to new concepts in science education. Both approaches ought to be considered in the context of mathematics and science connections.

Table 13

*Summary of Phase 2 (Continuum Model)*

<table>
<thead>
<tr>
<th>Mathematics focus</th>
<th>Balanced</th>
<th>Science focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Categorization based on lessons’ alignment with district curricula</td>
<td>Molly1, Molly2, Molly3, Stacy1, Stacy3</td>
<td>Stacy2, Steve1, Steve2, Steve3, Steve4</td>
</tr>
<tr>
<td>Molly4/Stacy4, Maria1, Maria2, Maria3, Maria4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Categorization based on lessons’ alignment with state standards</th>
<th>Molly3, Maria1, Maria2</th>
<th>Molly2, Molly4/Stacy4, Maria3, Maria4, Stacy1, Stacy3</th>
<th>Molly1, Stacy2, Steve1, Steve2, Steve3, Steve4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly3, Maria1, Maria2</td>
<td>Molly2, Molly4/Stacy4, Maria3, Maria4, Stacy1, Stacy3</td>
<td>Molly1, Stacy2, Steve1, Steve2, Steve3, Steve4</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* This table shows findings for the observed lessons and not for the unit plans associated with some lessons (e.g., Molly3, Maria1).

**Analysis of Phase 3 (Types of Integration)**

In the third reading, the researcher examined the arrangement of mathematics and science topics in the observed lessons. This reading was guided by Hurley (2001); the focus differed from the first and second reading because these readings did not consider how mathematics and science topics were presented in the lesson. In this reading, the researcher focused on *how* each discipline was taught, rather than on *what* was taught. Through this reading, the researcher sought to learn about the degree of fusion of the two
disciplines in the lessons previously identified along the continuum of mathematics and science integration (Huntley, 1999; Lonning & De Franco, 1997).

As stated earlier, this third reading was guided by Hurley (2001), who described five types of integration: Sequenced, Parallel, Partial, Enhanced, and Total integration (see Table 8 in Chapter 4 for the description of each type of integration). Hurley ranked these forms from the least to the greatest level of integration (Sequenced being the least integrated and Total being the most integrated). The researcher used Hurley’s ranking to examine the range of separation of mathematics and science topics in the lessons.

**Sequenced Integration (SI).** Because the researcher interpreted SI to refer to a team of teachers (or possibly one teacher teaching two subjects) working together to develop and teach sequenced lessons, there were no two lessons observed in this study that were part of this type of sequencing. Some unit plans involved multiple lessons, and some lessons involved multiple periods, but these units or multiple periods were not observed by the researcher in their entirety. The researcher was only able to observe one lesson from each unit or series of periods. Since each teacher was asked to present four lessons, this may have been interpreted as indicative of four unassociated lessons.

The evidence of this latter conclusion was the lesson presented by Stacy and Molly, the Molly4/Stacy4 lesson, which these teachers co-presented, but not without first asking the researcher for permission to teach the lesson together. The observed lesson was preceded by lessons in Molly’s and Stacy’s classrooms. However, the data did not include details necessary to make appropriate conclusions with regard to the sequencing of topics in these lessons. It is possible that these preceding lessons were coordinated by
these teachers but it is unclear if the lessons connected mathematics and science or how they were planned or delivered.

**Parallel Integration (PI).** Similar to SI, the researcher interpreted this form of integration to refer to a team of two or more teachers working together to develop and present lessons through parallel concepts. Using this interpretation, the researcher found no indication in the data of a deliberate attempt to plan and teach lessons in this form by two or more teachers. As was stated earlier with respect to SI, the lack of evidence of PI may be due to teachers’ interpretation of their role in the study. Each teacher was asked to present four lessons in mathematics and science connections. This may have been interpreted as separate, individual lessons. The absence of SI and PI may also be related to the teachers’ limited past experiences with collaborative projects involving colleagues in disciplines other than their own.

**Partial integration.** The researcher interpreted *Partial* integration to refer to one teacher (or possibly a team of teachers) attempting to teach both mathematics and science in one lesson. This lesson would have to involve two main components: 1) a mini-lesson focusing on only one discipline and separating mathematics and science, and 2) a larger lesson component in which mathematics and science were taught together. For this integration type, the researcher presents four lessons by the mathematics teachers, followed by four lessons by the science teachers.

**Mathematics teachers.** *Partial* integration in lessons taught by mathematics teachers could involve mini-science or mini-mathematics lessons, followed by activities combining mathematics and science. For example, a lesson in this category could start
with a mini-mathematics lesson in which students reviewed subtraction of decimals (e.g., 219.5 – 165.1). Then, the lesson could continue with a hands-on activity in which students subtracted decimals to calculate the weight of water displaced by boat-shaped objects of varying weights (e.g., 219.5g (water + cylinder) – 165.1g (cylinder)). This lesson could then conclude with an inference about the relationship between the weight of a sinking object and the weight of water displaced by that object. Similarly, a mini-science lesson about natural resources could be conducted in the beginning of class with no connection to mathematics, followed by an activity regarding the geometry of crystals.

As shown in Table 14, mathematics teachers taught four lessons (Molly1, Molly2, Molly3, and Maria3) that involved mini-science lessons in the first few minutes of the period. These mini-science lessons focused on definitions of scientific terms (e.g., element, compounds), diagrams (cells, papillary lines), scientific videos (forensic science, mining industry), and online resources (classification of trees). There was no evidence in the data indicating that teachers had pre-planned connections of mathematics in these mini-lessons. The intent of these activities was to present the science, rather than the mathematics.

Table 14

*Partial Integration and Phase 2*

<table>
<thead>
<tr>
<th>Integration type</th>
<th>Mathematics focus</th>
<th>Balanced</th>
<th>Science focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial</td>
<td>Molly3</td>
<td>Molly2, Maria3, Stacy1</td>
<td>Molly1, Stacy2, Steve1, Steve3</td>
</tr>
</tbody>
</table>

*Note.* This classification involved alignment with state standards rather than the district curriculum.
For example, Molly taught three lessons (Molly1, Molly2, and Molly3), which began with mini-science lessons before mathematics and science were taught together. In the Molly1 lesson, students watched a video on forensic science before engaging in an exploration, a classification, and a class summary of their papillary lines. In the Molly2 lesson, students identified basic parts and functions of an animal cell before engaging in a hands-on activity that related the maximum area of a polygon to a constant perimeter (cell membrane) to the shape of a circle (cell). In the Molly3 lesson, students watched a video about modern mining and talked about natural resources before calculating profit, cost, and revenue as owners of a cookie mine.

Similar to Molly’s lessons, the Maria3 lesson began with an activity that focused on tree identification. Students named a tree in their school’s courtyard using the tree’s geographic location, shedding patterns, and leaf shape. There was no indication of a deliberate intent in this mini-science lesson for the students to study mathematics. After this initial activity, students engaged in activities where the separation of mathematics and science was difficult to make. In other words, mathematical activities occurred in the context of science, not intended to be separated from that context. Students measured the circumference of a tree in the school courtyard, calculated the diameter, and estimated the age of the tree using the diameter and an appropriate growth factor provided by the teacher. The lesson concluded with an inference relating the age of a tree to its diameter and circumference.

*Science teachers.* Similar to mathematics teachers, science teachers also used science-focused introductory activities in their lessons (Stacy1, Stacy2, Steve1, and
Steve3) before engaging students in connecting mathematics and science. These activities involved reading packets (Stacy1 and Stacy2) and Power Point presentations (Steve 1 and Steve 3) to present material and concepts related to the lesson. Steve prepared his own presentations, and Stacy used materials from outside sources. If a visitor had walked into the classroom during these activities, s/he would not have been able to infer that the lesson intended to integrate or connect science and mathematics. However, when students calculated their weights on planet Neptune by multiplying two decimals in a lesson on gravity (Weight = Mass x Gravity), then the science in the activity was not considered separate from mathematics. In this case, science and mathematics occurred together.

The Stacy1 and Stacy2 lessons began with a reading packet of scientific content related to each lesson. Then, students shared answers to the multiple-choice questions presented in each packet. The questions involved scientific facts, rather than mathematics. In both lessons, the reading packets were followed by activities that involved both disciplines. For instance, when Stacy assisted students with the placement of decimals along the number line (bathroom tissue paper) in Stacy1, each decimal represented a separate event in the geological history of the Earth, and was not removed from its scientific context. However, if Stacy had conducted a mini-mathematics lesson about decimals before she connected each decimal to a major geological event, then this mini-lesson could be considered to be separate from science.

In the Steve1 lesson, the teacher began the class with a discussion of covalent and ionic compounds. The teacher first asked the students to identify different covalent
compounds, and then focused on the definition and chemical properties of ionic compounds. Next, students applied their knowledge of least common multiples and positive and negative numbers in the latter part of the lesson to balance ionic compounds. Similarly in the Steve3 lesson, the teacher conducted a mini-science lesson focusing on work and energy before engaging students in reasoning about the impact of the mass and velocity of an object on its kinetic energy. This lesson was observed the day classes resumed after spring break, and the teacher used this mini-lesson to purposefully revisit topics introduced to students prior to the break.

As shown in Table 14, evidence of Partial integration was found in lessons identified as “mathematics focus,” “balanced,” and “science focus” in Phase 2. The researcher inferred that Partial integration could occur in lessons when the focus of instruction centered on one discipline and those with a focus on more than one discipline. This observation indicates that some balanced lessons may not be seamless in their presentation of mathematics and science. There may be equal or comparable focus on the learning objectives in mathematics and science, which is desirable; however, a “balance” of the learning objectives may not be require a ‘seamless’ lesson.

**Enhanced Integration (EI).** Hurley (2001) described EI as one discipline being “the major discipline of instruction, with the other discipline apparent throughout the instruction” (p. 263). Because Hurley suggested that the degree of integration increased between Partial integration and EI, the researcher identified EI in lessons which did not involve mini-science lessons or mini-mathematics lessons. In these lessons, mathematics was used to teach science or science was used to teach mathematics. Because one
discipline dominated in EI, the researcher inferred that lessons that had been categorized as “Mathematics focus (mathematics with science)” or “Science focus (science with mathematics)” in Phase 2 qualified as being appropriate for examination in this category.

Lessons categorized as EI prioritized instruction in one discipline. This emphasis was observed when teachers built on their students’ existing mathematical skills to teach new science material. Similarly, when science was not a necessary component of the lesson and was used only as a context for mathematics, then lesson were considered as possible examples of EI.

**Mathematics teachers.** *Enhanced integration* (EI) in lessons taught by mathematics teachers could involve a science-focused lesson with mathematical procedures being utilized throughout the lesson. It could also be a mathematics-focused lesson using science to provide a real life context. An example of EI was a science lesson about mass and weight, in which students used multiplication to perform the necessary calculations in the lesson.

As shown in Table 15, lessons that implemented EI in the mathematics classroom were the Maria1 and Maria2 lessons. The Maria1 lesson was classified as EI because there was no indication of a mini-mathematics or mini-science lesson being conducted in isolation from the other discipline, and the instructional focus of the lesson was on mathematics more than science. If the students were observed discussing concepts in geology, climatology, or the environment in the lesson, then this lesson could have been considered less focused on mathematics and possibly reclassified in a different category.
In the Maria2 lesson, the scientific content of the lesson related to physical science (motion, force, gravity, energy), but the teacher’s instructional focus was mathematics. In this case, the majority of the lesson involved activities in data collection, modeling with scatter plots, the formulation of equation for lines of best fit with graphing calculators, and discussions of slope and intercepts. Similar to the Maria1 lesson, this lesson was conducted in the context of science, and was not classified as Partial integration due to the scientific context of all the mathematical activities in the lesson.

Table 15

*Enhanced Integration and Phase 2*

<table>
<thead>
<tr>
<th>Integration form</th>
<th>Mathematics focus</th>
<th>Balanced</th>
<th>Science focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced</td>
<td>Maria1, Maria2</td>
<td></td>
<td>Steve2, Steve4</td>
</tr>
</tbody>
</table>

*Note.* This classification involved alignment with state standards rather than the district curriculum.

**Science teachers.** *Enhanced Integration* (EI) was identified in science classrooms when teachers’ expectations regarding mathematics were limited to the students applying mathematical skills to learn new scientific material. Instruction in such lessons was interpreted as being science focused.

The researcher identified two lessons taught by science teachers as EI: Steve2 and Steve4. In the Steve2 lesson, students dropped *Mentos* candies in soda bottles and investigated the amount of gas released in the resulting chemical reaction. In the Steve4 lesson, students designed roller coasters, and investigated the energy transfer of an object dropped from the top of a roller coaster. Both activities utilized students’ mathematical skills for a scientific purpose.
As shown in Table 15, four “mathematics focus (mathematics with science)” and “science focus (science with mathematics)” lessons from Phase 2 were classified as EI. These lessons prioritized the learning objectives in one discipline. That is why lessons that were classified as “balanced” in Phase 2 were not classified as EI in Phase 3. The “balanced” lessons showed clear evidence of equal treatment of the learning objectives in mathematics and science, and, thus, would not be appropriate for examination as examples of Enhanced integration.

**Total integration (TI).** TI was identified in the Stacy3 lesson. This lesson provided students with the opportunity to extent their knowledge in both mathematics and science, which is the reason why it was considered as superior to Enhanced integration. It was not considered to be Partial integration because the lesson lacked evidence of a mini-science or mini-mathematics lesson intended by the teacher to separate these disciplines. Similarly, in the Maria4 lesson, students engaged in a lesson which enabled them to learn about a scientific technique of population estimation through tagging (sampling), while they reasoned with ratios, proportions, and recognized accurate vs. inaccurate estimates in scientific contexts.

The researcher observed that the Stacy3 and Maria4 lessons utilized concepts that were common to mathematics and science curricula (volume, measurement, and estimation), and perceived this finding to be important to demonstrate their understanding of the nature of TI. In other words, one possible way to teach mathematics and science seamlessly and with intended equality is through concepts common to both disciplines.
As shown in Table 16, “balanced” lessons were identified as *Partial* or *Total* integration in this third reading. As stated earlier, the classification *EI* would not be appropriate in “balanced” lessons because this form of integration lacked the intended equality of mathematics and science that is characteristic of “balanced” lessons.

Table 16

*Summary of Phase 2 and Phase 3*

<table>
<thead>
<tr>
<th>Integration type</th>
<th>Mathematics focus</th>
<th>Balanced</th>
<th>Science focus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Categorization based on lessons’ alignment with district curriculum</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>Molly1, Molly2, Molly3, Maria3</td>
<td>Stacy1</td>
<td>Stacy2, Steve1, Steve3</td>
</tr>
<tr>
<td>Enhanced</td>
<td>Maria1, Maria2</td>
<td></td>
<td>Steve2, Steve4</td>
</tr>
<tr>
<td>Total</td>
<td>Maria4</td>
<td>Stacy3</td>
<td></td>
</tr>
<tr>
<td><strong>Categorization based on lessons’ alignment with state standards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>Molly3</td>
<td>Molly2, Maria3, Stacy1</td>
<td>Molly1, Stacy2, Steve1, Steve3</td>
</tr>
<tr>
<td>Enhanced</td>
<td>Maria1, Maria2</td>
<td></td>
<td>Steve2, Steve4</td>
</tr>
<tr>
<td>Total</td>
<td>Maria4, Stacy3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 16 also depicts differences in the classification of lessons taught by mathematics teachers when the researcher considered the alignment of the lesson with the district curriculum (i.e., grade appropriateness of the lesson content). In this new context, all lessons taught by Molly and Maria were considered “mathematics focus.” Consequently, Maria4 was classified as “mathematics focus” and TI. This new classification indicated the possibility of “mathematics focus” lessons to be taught with
the intended equality of mathematics and science but not be considered “balanced” based on the lack of connection to the district curriculum in science.

The Molly4/Stacy4 lesson is not shown in Table 16. This lesson was not found to be *Sequenced* integration because the lesson observation involved a single period, with one lesson plan developed for this lesson. This lesson was also not found to be *Parallel* integration because it was a single lesson and did not involve a series of lessons presented simultaneously in both disciplines through parallel concepts. The lesson could also not constitute *Partial* integration because each activity in the lesson involved both mathematics and science. The lesson began with students making predictions about the shape of a curve representing the spread of a hypothetical disease. Next, students collected data on an outbreak of a simulated disease. Finally, the class graphed the data and drew conclusions about the shape of the resulting scatter plot and the rate of spread of the disease.

Since the lesson lacked evidence of one discipline dominating over the other, the researcher could not classify this lesson as an example of *Enhanced* integration. With its focus on the learning objectives in mathematics and science, this lesson was most representative of *Total* integration. If presented by one teacher, it would have been considered an example of *Total* integration. However, this lesson was co-presented by two teachers, Stacy and Molly, who divided instruction in accordance with their area of professional expertise. Stacy facilitated learning during the data collection activities and Molly oversaw student activities in graphing and slope representation. This division of instruction lowered the degree of separation of mathematics from science in the lesson.
Summary. As shown in Table 16, the appropriateness of content connections for the school district curriculum is an important element of integration. In this third reading, most lessons were identified as Partial integration, and only one lesson was identified as Total integrated. These results were dependent upon the lessons’ relevance to the school district curriculum in science and mathematics. Partial integration involved a purposeful separation of the discipline in a lesson through mini-science lessons. These mini-science lessons occurred in the beginning of eight lessons. This form of integration was observed in three types of lessons identified along the continuum (mathematics focus, balanced, and science focus). Enhanced integration was not observed in lessons identified as balanced.

Results for Research Question 2

Research Question 2: What are GK-12 middle school mathematics and science teachers’ perceptions and attitudes about mathematics and science integration?

The results presented below address two components of this research question: teacher perceptions of integration and teacher attitudes about integration. The researcher defined perceptions as ways of thinking about, interpreting, and understanding of mathematics and science integration. Teacher attitudes were revealed in teacher actions and dispositions toward integration. The analysis of data for this research question involved classroom observations, interviews, artifacts and survey. The theoretical framework that guided the analysis of the first research question was relevant to the analysis of this question. Teacher perceptions and attitudes of integration examined in the data informed the researcher’s understanding of the connections that were made in the
study. The results for mathematics teachers are presented first, followed by the results for science teachers.

**Perceptions and Attitudes of Mathematics Teachers**

**Perceptions of integration.** Both mathematics teachers perceived mathematics and science integration as the teaching of two lessons--one in mathematics and one in science -- concurrently. Molly described integration as a way “to simultaneously teach two topics or have them like bounce off each other, get some math concept out of a science lesson or some science concept out of a math lesson, at the same time.” Maria defined integration as “teaching both science and math through the same lesson, and hoping they [students] will get the same, hoping they get what they are going to need from both subjects that way.”

Molly and Maria perceived ‘integrating’ and ‘connecting’ as related, but not necessarily synonymous. By suggesting that integration involves two lessons taught together, they emphasized the need for discipline-specific objectives in integrated lessons: one for mathematics and one for science. In contrast, connecting was also perceived as “using” science to teach mathematics, with a focus on meeting the learning objectives in mathematics, but not necessarily in science. Molly presented this distinction between connecting and integrating as follows:

I guess I feel like integrating means more than connecting. I don’t know if that’s right, but I feel like a connection means like, “Here is your math and here is where it could be used in science,” like a connection, and integrating means
you’re actually having a whole lesson in science and a whole lesson in math at the same time.

Maria made a similar distinction between connecting and integrating. In her view, connecting involved two disciplines in one lesson supporting one another. In contrast, integrating involved two lessons being taught together, with two sets of learning objectives for each lesson. This is what she said about connecting in the post-study interview:

So the students know that it’s not just, “Ok, this is math, finding diameter is strictly math.” Because we used it in science, we used it to estimate the age of a tree, so that they could see that it does, it connects, everything connects, and the kids need to see that. But when I tried to make that connection without them seeing it, it doesn’t happen. It stops short … They needed to do it, they needed to see that, in order to do this in science, they need this in math, and I think that’s what we’re doing when you say connecting. We’re letting the kids take the two subjects and understand that one helps the other.

Comfort with integrated instruction. The interviews revealed mathematics teachers’ sense of discomfort with the teaching of science in mathematics lessons. Before the study, Molly said, “I think it could be [integrated]. I’m really scared, but I think it could be.” The sense of being scared of integration was related to Molly’s past teaching experiences, which may not have involved extensive integrative efforts. When asked to describe an integrated lesson that she delivered prior to the study, Molly said, “Honestly, I don’t think I have ever delivered a lesson that integrated math and science.”
In reference to Molly’s experiences with the integration of science in mathematics, Stacy said:

I think they are separate right now, totally separate, like, I teach science, Molly teaches math, and what was interesting was when I was talking to Molly about the forms that we had to fill out [survey], I think the one question said, *How do you integrate math in your science?* So, that’s easy, but then there was, *How do you integrate your science into math?* and Molly’s like, ‘Well, I don’t do that’ and I think she doesn’t do that. She’s the math teacher and that’s it, and there’s no real science connection with that, and with me, I’m the science teacher but there is a little math connection … so I think right now they’re taught separately.

Molly’s four lessons were new lessons that she found and adapted for the purpose of the study. After the study, she said, “It’s challenging for me because I’m not particularly knowledgeable about science, so to make a lesson is harder … It takes a while. It takes a lot of work. So it’s challenging.” However, based on her post-study interview and survey, the researcher inferred that Molly’s perception of her practice of integrated teaching evolved over the course of the study. For example, at the end of the study, she was able to give two examples of integrated lessons that she taught in the past (Molly2 and Molly4), but the pre-study survey showed no evidence of integrated lessons. She also increased her responses from 2 (disagree) to 3 (agree) on seven statements (1, 2, 3, 6, 17, 19, and 21) on the Professional Practices Survey (survey item 1), from 3 to 4 on statement 15 and from 1 to 2 on statement 10. See Table 17 for results regarding this item on the survey for all teachers. The survey is presented in Appendix E.
Table 17

*Teacher Responses for Professional Practices Survey*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly</td>
<td>1  2  3  4  5  7  8  9  11  14  15  16  17  19  20  21</td>
</tr>
<tr>
<td>Pre</td>
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</tr>
<tr>
<td>Post</td>
<td>3  3  3  2  2  3  3  2  2  3  4  1  3  3  3  3</td>
</tr>
<tr>
<td>Maria</td>
<td>3  2  4  4  2  2  3  2  3  4  2  2  2  3  2</td>
</tr>
<tr>
<td>Pre</td>
<td>2  3  3  3  3  3  3  3  2  3  4  2  2  2  3  3</td>
</tr>
<tr>
<td>Post</td>
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<tr>
<td>Stacy</td>
<td>2  3  3  2  2  2  1  3  2  3  1  3  1  2  3  3</td>
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<tr>
<td>Pre</td>
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</tr>
<tr>
<td>Post</td>
<td>2  3  0  0  3  3  2  3  3  2  3  2  2  3  3  3</td>
</tr>
</tbody>
</table>

Note. The responses stand for “strongly disagree” (1), “disagree” (2), “agree” (3), and “strongly agree” (4).

Maria’s attitude about integration was similar to Molly’s. Before the study, she said the following, “I’m afraid of science, I’m not going to say I’m not afraid … but I’m always open to learning … I’m not bringing science expertise to the table. I’m a math teacher and I can do math and I’m comfortable with math, but the science part, I think will, is going to be a challenge for me.” In the post-study interview, she said, “I don’t think of afraid of it any more. I used to be afraid. Now that I’ve tried it, and I know I can do it, I’m not afraid of it. So, I could see myself doing more of it in the future. I’m still going to be a math teacher … But, I think, now I’m comfortable pulling in science and using science to help deliver that content.” Her responses on the Professional Practices Survey (see Table 17) showed 11 3’s and 4’s (agree/strongly agree) out of a total of 16 statements, and five of these responses increased from a 2 (disagree) on pre-study survey.
The perception of integration as a “challenge” was expressed by both teachers. Molly used the word “challenge” to describe the meaning of integration on both surveys. She first said, “It poses a challenge for me. I do not feel prepared to integrate the two subjects in my classroom, but I look forward to learning how to do that.” In her post-study response, she supported this view of integration by saying, “It basically means a challenge to me - an interesting and exciting one - but still a challenge.” The interview data revealed that the challenge of integration for both teachers was related to multiple aspects of teaching, including how well-prepared teachers felt to teach science content, how well they could integrate science into mathematics, and whether or not they were going to meet the curricular goals in mathematics for their grade level when some of the class time was going to be devoted to science. Six lessons in the study involved multiple class periods, and five of them were conducted at the end of the school year, after state testing. Maria said, “What if I wasted two weeks on trying to do it this way and it didn’t work … I’m fearful of new things.” Molly said:

I’m worried about how I would fit it [science] in … because I don’t have enough time to get them to understand the math I need them to do, I can’t imagine fitting science in, too, unless … of course, if it helped them with their math that would be great, but that’s the part that I don’t get, how we’re going to bring science in here to help them with their math. I could see how math helps them with their science. I’m not understanding how science’s going to help them with their math.

As stated earlier, the perception of integrated teaching as a challenge was reflected in the shared attitudes and perceptions of mathematics teachers about their
expertise in science. Both teachers emphasized their comfort level with mathematics content over science content. Maria said, “I’m anxious to [integrate]. I’m not a science person. I’m a math person.” Molly said, “I was never a science person in school.” In the study, both teachers selected lessons that they felt most comfortable teaching—not necessarily lessons that were appropriate for the grade level, and aligned most closely with the school science curriculum. As was described earlier, both teachers shared a perception of having a weak proficiency in physics and chemistry and presented seven lessons in life and earth science instead. Maria said:

> I don’t know if I’m really proficient, if you would say, in any field in science. I’ve never really studied it except in high school. I believe I had a bio class in college, but that’s a long time ago. So, I’m not very proficient in science.
>
> Everything I did this year with this program I had to research and learn, except for the trees. I knew you judged the trees by the rings.
>
Mathematics teachers’ attitudes about their familiarity with science content were also reflected in surveys. For example, in response to the survey statement, *I feel I have sufficient background in mathematics and science to integrate both in lessons*, both mathematics teachers disagreed with this statement on pre- and post-study survey. Molly’s post-study interview response further reflected this attitude, when she said, “I will be able to do it, but it is not that I have sufficient knowledge. It will require much research on the science concepts.” Similarly, Maria stated, “In certain areas I feel comfortable integrating math and science, but my science background is very limited and I can’t say I have a ‘sufficient’ background.” Data from the artifact collected at the last
workshop in May, 2012 revealed that Molly wished to learn more about “age appropriate science lessons” in the future.

Integration may also have been perceived as being challenging because mathematics teachers perceived their expertise in integrated teaching to be limited. Molly said that her students were “shocked” to be experiencing science in her classroom, and that she never tried to integrate science and mathematics prior to the study. Neither teacher used her own lessons in this study, but rather adapted them from a variety of sources. These lessons were being taught for the first time in this study. Molly used resources from the National Science Teacher Association, and the GK-12 program website (www.csam.montclair.edu/gk-12). Maria adapted NCTM lessons from the Illuminations website (www.illuminations.nctm.org) as well as one from the Center for Innovation in Engineering and Science Education (www.ciese.org). Both teachers implemented lessons with minor alterations (e.g., videos, demonstrations). In contrast, all four of Steve’s lessons were ones that he had taught previously in his classroom. This strategy indicated that Steve perceived his lessons to be appropriate for the study and was able to use them as a foundation for his efforts to connect mathematics and science. Maria and Molly did not appear to have a similar foundation.

In the study, both math teachers had a positive attitude about integration and wanted to learn to integrate because they felt that integration was beneficial for their students. For Molly, science provided a “fun and interesting” context for mathematics. When asked if she thought science helped her students with mathematics, Molly said, “I do, the student that said, ‘Math is fun,’ I mean, it was fun because we added this whole
aspect to it, so I guess it does.” In this case, the new, “fun” aspect of mathematics meant an engaging simulation of disease spread, which Molly and Stacy connected to a lesson on slope and functions in the Molly4/Stacy4 lesson. For Maria, hands-on activities and experiments provided students, especially special education students, with an authentic, meaningful context for mathematics. The researcher was invited to observe three lessons in a class with over ten special education students. Maria perceived science connections to be beneficial for these students, and said, “I thought the kids did very well with it. I think they enjoyed it. I think that genuine data made it real for them and they owned it.” Maria did not believe that students would always walk out of her classroom thinking that they had learned both mathematics and science, but she supported integration and connections. She explained:

I think, my attitude is I like it. I like to see them make connections. Across the board, obviously, I can do much higher level with my honors students. Um, but one thing that stayed constant from my lowest level learners to my highest is the discovery that, and their own data collection that they were doing, whereas traditionally in the past, I’d give, here you go, here is data, which really meant nothing to them. It was a bunch of numbers and this was, they made it their own and I think that really grabbed my disability students and held my honors students.

Here is what Molly said about her students’ reaction to science in the mathematics classroom:
I think, I don’t know why, but they seem so excited by it, like, they, every time when, like, one of these went well, whether it was mine or Felicia’s and Julie’s lesson [both Fellows], if it was really like both math and science, then they’d all be like, “This is crazy, I feel like I’m in science,” and they would say things like, “Why are we doing this in math?” Like, it just made them more interested and excited about learning, whatever it was.”

This influenced Molly’s perception of the role of science in her lessons because it enabled her to observe and evaluate her students’ reaction to activities involving hands-on, discovery-based learning. In interviews, she frequently referred to science as “fun” and “interesting,” and described the role of science in her lessons as a context that made mathematics learning more meaningful. Maria’s view of the role of science was similar. She “used” scientific processes and content to teach mathematics.

Overall, mathematics teachers had a positive attitude toward integrated instruction of mathematics and science and wanted to learn to integrate these subjects, but perceived their expertise as deficient in science content knowledge. Despite these attitudes and perceptions with respect to their knowledge of science, however, lessons presented by Molly and Maria involved “good” science teaching methodology of hands-on explorations, were related to state standards, and resulted in new lessons for both teachers. Both teachers felt that science brought an element of “fun” and “authenticity” into the mathematics classroom, and were positive about the expected benefits of future professional development in integrated instruction and their ability to integrate these disciplines.
Perceptions and Attitudes of Science Teachers

Perceptions of integration. Science teachers’ perception of integration involved both disciplines being taught together, without the necessity of distinguishing the concepts as being either mathematics or science. Both teachers referred to integration as a ‘seamless’ blend of mathematics and science and intended to teach lessons that were well-balanced. When asked in the post-study interview if they would teach different lessons if asked to integrate instead of connect, both teachers indicated that they would not have selected different lessons. This indicated that their practices of connecting were related to their understanding of integrating. In contrast, both mathematics teachers made a distinction between connecting and integrating in this interview.

In the Steve2 lessons, Steve described his perception of integration as follows: “They [students] were using math to do science, they were doing science with math, and to me that seems like (…) as close as you can get, they were doing both seamlessly.” Stacy shared this perception, when she described the Stacy3 lesson: “I think, it would be well-balanced, where it came as equally, they’re represented, not too much science, and not too much math.” Stacy also said, “I would like it to be so that they don’t even realize the distinction, you know what I mean? It’s just introduced as one thing and they don’t make that distinction that it’s math and that it’s science, like that.”

An example of science teachers’ perception of integration as being ‘seamless’ was also illustrated in Steve’s description of integrated instruction: “You’re handling both science and math within the lesson, the kids are easily moving from one to another … the kids are just doing it seamlessly. They are not saying, ‘Oh, this is science only. This is
math only.’ It’s just, ‘I’m using either or to do this and that.’” When asked about the meaning of integration, Stacy made a comment that concurred with Steve’s view of integration. She said, “Integration means combining the two seamlessly, so that students cannot say it was one subject with aspects of the other. The line between the two should be blurred perfectly.” This perception of integration is consistent with the meaning of Total Integration proposed by Hurley (2001) or Integration by Huntley (1999), when mathematics and science are taught in intended equality.

In the interviews, science teachers suggested that integrating involved an equal or comparable amount of the two disciplines in a lesson. For instance, Steve described his science lessons as being “math-heavy” and Stacy frequently referred to the “amount” of each discipline in her lessons. When asked how well mathematics and science were connected in her lesson, Stacy said, “For me, I think, it would be a well-balanced, where it came as … equally, they’re represented, not too much science and not too much math.” In her post-classroom observation interview regarding the Stacy4 lesson, she said, “Out of all the lessons that I have done and been observed I really think this one has an even amount (…) This I feel like it was kind of straight down the middle. Like there was the huge amount of science and then the huge amount of math.” In the context of the continuum model, a lesson “straight down the middle” would be considered integrated.

Despite differences among mathematics and science teachers’ attitudes and perceptions of integrated teaching, all four teachers shared a common perception of integration as it related to connections. The researcher made this inference based on the artifacts collected as part of the January, 2013 monthly workshop. In one activity,
teachers were asked to construct a rubric for assessing the mathematics and science connection in a hypothetical lesson. The seventh grade team (Maria and Steve) assigned the highest score to a lesson with “lots of” mathematics, “lots of” science, a “seamless” blend of these disciplines, and an “engaging” presentation. In sixth grade (Molly and Stacy), teachers assigned the highest score to a lesson described as the “integration of math and science” with “math and science content inter-related,” “both necessary for the success of the lesson,” and “equal amounts” of each discipline. Although teachers were not advised to focus on integration in this activity, both rubrics included characteristics of integration (Huntley, 1999; Hurley, 2001). This indicates that they perceived integration as a high degree of connection.

The perception that mathematics and science could be taught seamlessly in the classroom, with the disciplinary lines blurred completely, was not shared by Maria. In contrast to Stacy and Steve, Maria questioned the view of ‘seamlessness’ of integration in the post-study interview by saying, “You can’t put them together yet, because they are separate. They’re separate. They are two separate subjects, and that could be just because I was raised that way or taught that way. You can connect them, but I don’t know if you could ever teach them as one thing.” This teacher perceived her role in the classroom to be one of a mathematics teacher, not a science teacher. Interview data for the science teachers did not reveal a similar perception of mathematics and science as being two separate subjects that could not be taught ‘seamlessly.’

In her descriptions of the degree of connections in the presented lessons, Maria was also the only teacher who did not focus on the “the amount” of mathematics and
science in her lessons. When asked how well she connected mathematics and science in her lessons, she often talked about her students’ learning, and whether or not she reached her learning objectives for these lessons, rather than focusing on the amount of science in each lesson. On the other hand, Molly’s approach was found to be similar to Stacy’s or Steve’s rather than Maria’s, and focused on the progression and amount of mathematics and science in the lessons. For the Molly4 lesson, she said, “If you asked the students whose lesson was [Stacy’s or Molly’s], I think maybe they wouldn’t all have the same answer. I think like some, they wouldn’t know, I think they would think it was like a joint thing.” When asked about the connection in the Molly1 lesson, she said, “I think they did connect well (…) it wasn’t like, ‘Boom, that’s the end of science, let’s start the math.’ I feel like they did just go together, because it just made sense for them to be together.”

**Comfort with integrated instruction.** Science teachers engaged in the teaching of mathematics and science connections prior to the study, and were able to give examples of integrated lessons on the pre- and post-study survey. On the pre-study survey, Stacy presented the Stacy2 lesson as an example of integration; Steve presented a lesson that was not observed by the researcher. On the post-study survey, the Stacy3 lesson was used as an example of integration, and Steve described an entirely new lesson that had not been used at any point in the study or shown as an example on the pre-study survey. The researcher inferred that science teachers perceived their own past experiences with mathematics in science as examples of integrated instruction.
As shown in Table 17, the survey results of the Professional Practices Survey revealed that science teachers felt that they often helped students recognize mathematics in science, but mathematics teachers disagreed with the statement *I often help students see science in mathematics* before the study, and only one agreed with the statement after the study. Collectively, the science teachers presented five lessons that they had taught in the past, and Steve’s lessons were all taught in the past. The changes that had been made to these lessons before the classroom observations were completed independently of this study and were based on the teacher’s experiences with these lessons in previous years. In sixth grade, three new lessons were presented, and one in collaboration with the sixth grade mathematics teacher. These lessons were aligned with the district’s science curriculum and developed for the purpose of a continued use and implementation in subsequent years.

**Survey Results (Combined)**

**Perceptions of integration.** As shown in Table 18, teacher responses to the questionnaire items varied per item, although certain patterns were found in these results. For instance, there is evidence of three teachers not feeling confident in their background knowledge to integrate mathematics and science. Similarly, all four teachers felt that integration was not most appropriate for talented and gifted students, and ought to be used in other contexts. There were also other results of significance to this study, which indicated several important similarities among teachers. These results are presented below in the order of the statements in the survey.
1. **Statement:** For many topics, integrating mathematics and science is a preferable method than teaching the content in separate lessons. Only one teacher (Maria) agreed with this statement on both pre- and post-study survey. Science teachers remained neutral, and Molly disagreed on the post-study survey.

2. **Statement:** I feel I have sufficient background in mathematics and science to integrate both in lessons. Three teachers (Molly, Maria, and Stacy) disagreed with this statement. Steve upgraded his response from Neutral to Agree.

3. **Statement:** I am aware of curriculum materials designed to integrate mathematics and science. Both mathematics teachers agreed with this item, whereas both science teachers disagreed.

4. **Statement:** There’s not enough time during most lessons to integrate mathematics and science content. Three teachers (Maria, Stacy, and Steve) disagreed with this statement. Molly agreed with the statement both times. Molly’s interview data supported this response.

5. **Statement:** Students get confused when mathematics and science are integrated in lessons. Two teachers (Molly and Stacy) strongly disagreed and Maria disagreed with this statement in their post-program response. These teachers changed their initial positions of Agree (Stacy), Neutral (Maria), and Disagree (Molly).

6. **Statement:** Classes for gifted students would be most appropriate place for integrating mathematics and science. On the post-study survey, all teachers either disagreed (Molly, Maria, and Steve) or strongly disagreed (Stacy) with this statement.
7. *Statement: Hands-on activities are more appropriate in science lessons than in mathematics lessons.* Both mathematics teachers disagreed with this statement, showing a consistent position in favor of hands-on activities in mathematics. Science teachers had a mixed reaction, with Stacy disagreeing at first and then changing her position to Neutral, and Steve doing the opposite. This mixed reaction by the science teachers could be related to their knowledge of pedagogical practices and pedagogical content knowledge in mathematics. Both teachers perceived their expertise in mathematics pedagogy as significantly inferior to science pedagogy.

8. *Statement: During talks with my colleagues and by observing lessons, it appears to me that integrating mathematics and science is common.* Both sixth grade teachers disagreed with the statement in their post-program survey, with one of them changing her position from Neutral (Stacy). The 7th-grade teachers responded Neutral on both surveys. These responses show the need for teachers to engage in collaborations, which are currently not perceived as common in the school.

In response to the statement, *I feel I have sufficient background in mathematics and science to integrate both in lessons,* one science teacher agreed with this statement on the post-study survey and was neutral about it on the pre-study survey. The sixth grade science teacher disagreed with this statement on both surveys and justified her attitude by stating, “Not sufficient background in math” on the pre-study survey, and “I feel that my background in 6th grade science is adequate, but I still rely heavily on the
math teacher [Molly] to provide me with instruction and guidance in some topics” on the post-study survey. As discussed previously, data indicated that this teacher worked closely with Molly, the sixth grade mathematics teacher, and referred to Molly’s views and opinions of student learning in mathematics in the interviews. Stacy addressed Molly’s curricular objectives in her science classroom. In at least two lessons presented in this study, Stacy consciously attempted to reinforce the mathematical skills of students also taught by Molly. See Table 18 for results regarding teacher responses to this item on the survey.

Table 18

Perceptions Toward the Integration of Mathematics and Science

<table>
<thead>
<tr>
<th>Teachers</th>
<th>Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly</td>
<td>1 2 3 4 5 6 7 8</td>
</tr>
<tr>
<td>Pre</td>
<td>N D D A D A SD D</td>
</tr>
<tr>
<td>Post</td>
<td>D D A A SD D D D</td>
</tr>
<tr>
<td>Maria</td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>A D A D N D D N</td>
</tr>
<tr>
<td>Post</td>
<td>A D A D D D D N</td>
</tr>
<tr>
<td>Stacy</td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>N D D N A D D N</td>
</tr>
<tr>
<td>Post</td>
<td>N D D D SD SD N D</td>
</tr>
<tr>
<td>Steve</td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>A N D D N D N N</td>
</tr>
<tr>
<td>Post</td>
<td>N A D D A D D N</td>
</tr>
</tbody>
</table>

Note. The responses stand for “strongly disagree” (SD), “disagree” (D), “agree” (A), “strongly agree” (SA), and “neutral” (N).

Comfort with integrated instruction. Despite some differences in teachers’ views of their past and present practices in teaching mathematics and science, there were some important similarities among the four teachers. For instance, the teachers agreed on
the pre- and post-study survey that they felt comfortable teaching with real-world data. In addition, in their post-program responses, these teachers either agreed or strongly agreed with the statement *I teach lessons that integrate science and mathematics* and *I teach interdisciplinary lessons involving science and mathematics.*

Table 19

*Comfort Level Averages Teaching Mathematics and Science Content*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Mathematics</th>
<th>Physical Science</th>
<th>Life Science</th>
<th>Earth and Planetary Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>2.8</td>
<td>1.6</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Post</td>
<td>2.9</td>
<td>2.1</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Maria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>3</td>
<td>1.1</td>
<td>1.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Post</td>
<td>3.1</td>
<td>1.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Stacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>1.8</td>
<td>2.6</td>
<td>3</td>
<td>3.6</td>
</tr>
<tr>
<td>Post</td>
<td>2.5</td>
<td>3.2</td>
<td>2.8</td>
<td>4</td>
</tr>
<tr>
<td>Steve</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>1.9</td>
<td>3</td>
<td>2.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Post</td>
<td>2</td>
<td>3.2</td>
<td>2.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

*Note.* The response 1 stands for “very uncomfortable,” 2 for “somewhat uncomfortable,” 3 for “somewhat comfortable,” and 4 for “very comfortable.”

As shown in Table 19, mathematics teachers felt more comfortable teaching mathematics topics than science teachers. This result can be explained by their educational background and experience. In science teaching, mathematics teachers felt least comfortable teaching physical science and most comfortable teaching life science. Science teachers’ comfort level with the teaching of physical science, life science, and earth and planetary science was comparable. Stacy felt most comfortable teaching earth and planetary science, and this field of science is a major component of the sixth grade
science curriculum. Similarly, Steve felt most comfortable teaching physical science, which constitutes the majority of the seventh grade curriculum.

Table 20

*Comfort Level Teaching Science Content Overlap with Mathematics Content*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Physical Science</th>
<th>Life Science</th>
<th>Earth &amp; Planetary Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molly</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Maria</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Stacy</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Steve</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note.* The response 2 stands for “somewhat uncomfortable,” 3 for “somewhat comfortable,” and 4 for “very comfortable.”

As shown in Table 20, the results of the *Comfort level with math and science content overlap* (topics 101, 102, and 103 on page 10 of the survey) suggested that mathematics and science teachers felt most comfortable teaching concepts that overlapped in mathematics and physical science, with science teachers exhibiting slightly more confidence in this context. Similarly, the results pertaining to teaching overlaps in mathematics and Earth and planetary science were typically “somewhat comfortable” and “very comfortable,” and here, the gap between science and mathematics teachers was very small, smaller than was the case in the previous category. Overlapping concepts in mathematics and life science were met with the least confidence by both mathematics and
science teachers; the mathematics teachers exuded more confidence in teaching overlapping concepts than the science teachers.

**Attitudes about integration.** Teachers’ pre-study and post-study responses to the semantic differential item on the survey suggest that mathematics and science teachers shared similar attitudes about integration. Specifically, survey data from the semantic differential revealed that all four teachers agreed that integration was *beneficial*, *active*, *good*, *changing*, and *expanding*. These adjectives were chosen from a group of 20 pairs of adjectives that were scored by each teacher. The five adjectives shown above received scores comparable to 4 and 5 on a 5-point scale. Mathematics teachers agreed that integration was *deep*, *exciting* and that we needed *more* of it, whereas science teachers agreed on such adjectives as *understandable*, *necessary*, *complicated*, and *jump in*. Collectively, these results indicated that teachers expressed a generally positive attitude toward integration.

**Summary.** The results of this study suggest that mathematics and science teachers perceived integration as a process characterized by the lack of dominance of one discipline over another discipline in a lesson. For mathematics teachers, this perception required a merge of two lessons, one in mathematics and one in science, into one lesson. Science teachers recognized integration in lessons blending two disciplines seamlessly. Unlike science teachers, mathematics teachers also differentiated between connecting and integrating. These teachers recognized lessons with connections as lessons with instructional focus dominated by one discipline. This implied that skills or concepts from
one discipline were being used to reach the learning objectives specified for the dominant
discipline.

Mathematics teachers and science teachers supported mathematics and science
connections in the classroom. However, mathematics teachers perceived their familiarity
with science content as low, particularly in content related to physical science, and were
less confident in their ability to teach integrated lessons than science teachers. They also
lacked familiarity with science content in the district curriculum and state standards.
Science teachers’ attitude about their ability to connect mathematics and science was
more positive, as was their familiarity with lessons involving connections of mathematics
and science.

In general, the instructional practices implemented in science classrooms lacked
emphasis on the development of the conceptual knowledge of mathematics. Instead,
Stacy and Steve often focused on the application of mathematical procedures in their
lessons. As was mentioned earlier, Stacy’s relationship with Molly enabled Stacy to learn
about Molly’s curriculum and her daily teaching efforts. Steve, however, did not share
this experience with Maria, which he described as follows:

Basic stuff [multiples] like that does come up, but the actual content I would
probably have to find what they’re supposed to know, because that stuff doesn’t
really come up, where teachers that aren’t necessarily familiar with what other
teachers actually have to teach. So, in order to be comfortable, I would have to
look and figure out what they’re supposed to be up to.
In this statement, Steve expressed interest in learning about mathematics teaching and curriculum. He also suggested that learning about mathematics pedagogy and content would be beneficial to his efforts to teach mathematics in his science classroom.

Mathematics and science teachers in this study supported integrated instruction and practices involving connections of mathematics and science. Thus, the researcher concludes that professional development opportunities, similar to those presented in this program, could serve as a useful platform for future efforts aimed at connecting and/or integrating these disciplines in the classroom, particularly those opportunities which support teacher collaborations.

**Conclusion**

This study involved two research questions. With the first research question, the researcher sought to describe the nature of the mathematics connections made by middle school mathematics and science teachers in the GK-12 program. Using the literature, the researcher examined the extent to which these connections represented integration. For the second research question, the researcher sought to learn about teacher perceptions and attitudes about integration. The findings related to the second question helped to inform the analysis of the first research question by providing important insights into why and how middle school teachers connected mathematics and science.

The results of data analysis revealed that mathematics and science teachers typically connected mathematics and science content, and that these connections were grade appropriate—aligned with the school district science and mathematics curricula for the given grade level—in mathematics and science in lessons taught by science teachers.
When taught in mathematics classrooms, science content was related to state standards but it typically misaligned with the district science curriculum for the given grade level. Mathematics teachers selected lessons based on criteria other than the science curriculum (e.g., science processes, mathematics content curriculum, field trips, state testing, and student interest). Consequently, science content connections were dominated by life science concepts, although the district science curriculum focused on concepts in physical science. Survey data showed that these teachers felt least comfortable teaching topics in physical science and most comfortable teaching topics in life science, and their lesson choices reflected this preference.

In addition to making frequent content connections, mathematics teachers made connections of mathematics content with science processes and teaching methods (e.g., inquiry and discovery-based learning, experimental science). These connections made lessons appear more seamless, and were frequently applied in mathematics classrooms. In science classrooms, connections of mathematics content and science processes and methods occurred in most lessons, but these connections typically focused on the teaching of science, not mathematics. Students applied mathematical procedures and skills to learn new material in science. Only some lessons involved learning objectives for mathematics, and these objectives were common to science and mathematics curricula (e.g., volume, large numbers, and rate of growth). Three lessons involved problem solving and thinking with mathematics. These lessons connected “good” mathematics teaching and science content.
The extent of integration of connections varied among teachers, with most lessons lacking the equality of focus on the learning objectives in both disciplines. Instruction in most lessons was dominated by one discipline, either mathematics or science. Six of the fifteen lessons showed evidence of a similar focus on the learning of new material in both subjects. In science classrooms, these lessons involved grade appropriate learning objectives, whereas in mathematics classroom, learning objectives were balanced but lacked alignment with the district curriculum.

An example of a lesson that fulfilled conditions for full integration presented in Phases 1, 2, and 3 was the Stacy 3 lesson. This lesson involved grade appropriate learning objectives in science and mathematics (Davison, Miller, and Metheny, 1995) and the instructional focus on learning was similar in both disciplines (Lonning and De Franco, 1997). This lesson exposed the synergist union of the two disciplines (Huntley, 1999), and lacked evidence of separation of mathematics from science (Hurley, 2001). It is important to note that this lesson involved all three types of connections described by Davison, Miller, and Metheny (1995): science content, process, and methods connections with mathematics content.

The instructional focus on grade appropriate goals of each lesson was related to teachers’ perceptions of integration and connections. Teachers shared a common belief that integration involved intended equality of focus on two disciplines. Mathematics teachers also made a distinction between integration and connections. Lessons that used either mathematics or science to teach the other discipline were viewed as connected. When two lessons, one in mathematics and one in science, were merged into one lesson,
then the resulting lesson was perceived as integrated. Science teachers, on the other hand, did not explicitly specify ‘dominance’ as a key element of integration but rather focused on the extent of seamless blending of two disciplines as evidence of integration.

This study showed that teacher perceptions of integration were reflected in the lessons. When asked to connect mathematics and science, mathematics teachers taught lessons that connected mathematics and science; most of their lessons focused on the learning objectives in one discipline (mathematics). New material in science was taught in many lessons, but this material was not aligned with the science curriculum. Thus, their lessons did not represent two lessons designed for the district curriculum and merged into one. Similarly, science teachers attempted to seamlessly blend mathematics and science, but this resulted in interdisciplinary and integrated instruction. This finding suggests that the pursuit of a seamless blending may not always result in integrated outcomes. What may be lacking in these lessons is the focus on the equality of instruction and learning of new material in both disciplines.

Teachers supported integration of mathematics and science and believed that the teaching of both disciplines was beneficial for students. However, this study revealed that mathematics teachers lacked confidence in and familiarity with district curricula and state and national standards in science. Similarly, science teachers lacked familiarity with mathematics standards, although their pre-study experiences with connections were more extensive than those of mathematics teachers. Both groups expressed interest in learning more about integrated instruction and collaborative work geared toward interdisciplinary connections and integrated teaching.
CHAPTER 5 – DISCUSSION

Educators have discussed the merits of teaching mathematics and science in an integrated way for decades (e.g., Berlin & White, 1994; Czerniak, Weber, Sandman, & Ahern, 1999; Jacobs, 1989; Mason, 1996; Pang & Good, 2000). Past reform initiatives in mathematics have recognized the connections between mathematics (NCTM, 2000) and science education (e.g., AAAS, 1990, 1993; NGSS Lead States, 2013; NRC, 1996), as well as by teacher education programs that focused on the integration of these disciplines (e.g., Berlin & White, 2012; Furner & Kumar, 2007). However, the literature offers few examples of studies that focus specifically on integrated science and mathematics instruction in K-12 classrooms (e.g., Basista & Matthews, 2002; Huntley, 1999).

This study built upon the existing research base to contribute important insights into how mathematics and science could be taught together in one classroom. That is, when teachers did attempt to connect mathematics and science, the researcher focused on what was being connected and precisely how it was being connected. Thus, one goal of this study was to explore the nature of the mathematics and science connections made by middle school mathematics and science teachers and to examine the extent to which these connections represented integrated instruction. This objective was achieved by analyses of data collected from classroom observations and teacher interviews.

In addition to supporting integration, the education community has also recognized differences in the disciplinary knowledge of mathematics and science, teacher knowledge within disciplines, school structure, and student assessment as possible obstacles to the successful implementation of integrated curricula (Frykholm & Glasson,
Thus, an additional goal of this study was to describe teacher perceptions and attitudes related to mathematics and science connections and integration. Identifying such attitudes and perceptions provided an opportunity to seek explanations regarding the nature of the mathematics and science connections teachers make in their classrooms and to better understand teacher practices regarding these interdisciplinary connections and integrated instruction.

The two research questions addressed were:

1a.) What is the nature of mathematics and science connections made by middle school mathematics and science teachers in the GK-12 program?

1b.) What is the extent to which these connections represent mathematics and science integration?

2.) What are the GK-12 middle school mathematics and science teachers’ perceptions and attitudes about mathematics and science integration?

This chapter discusses the key findings of the study, presents the implications of these findings for research, professional development, teachers, and school districts, describes the limitations and missing data, and proposes recommendations for future research and classroom practices.

**Discussion of Key Findings**

**Connections of Mathematics and Science**

 Teachers connected content in mathematics with content in science in the vast majority of lessons observed in this study. These connections abounded in science
classrooms as well as mathematics classrooms. In addition, mathematics teachers frequently connected scientific processes (e.g., questioning, hypothesizing, data collection, data interpretation, conclusions) and teaching methods typically associated with science education (e.g., scientific inquiry, discovery) to teach mathematics content. This finding shows that mathematics teachers support classroom activities focused on investigations of mathematics content in scientific contexts and using scientific inquiry. These activities are important for learning since they provide students with opportunities to become actively engaged in the classroom. Combined with content connections, process and methods connections enable students to engage in explorations of mathematics, science, or both, while also learning about the connections between mathematics and science.

In science classrooms, on the other hand, science processes and teaching methods were used to achieve mathematical learning objectives in some lessons, but activities that focused on inquiry and discovery were frequently used to teach content in science rather than mathematics. Students used mathematics to study science, and their mathematical skills were essential to the success of these lessons, but these skills were not intended to be introduced to students for the first time in the observed lessons. This finding suggests that, while science teachers used “good” science teaching methods and processes in their lessons, these methods were used to teach scientific rather than mathematics concepts. This observation reveals that, while mathematical procedures play an important role in science instruction, the teaching of new material in mathematics is not typically the focus of science instruction.
This finding further suggests that the connections of mathematics and science, particularly in mathematics classrooms, support the implementation of activities involving experiments, investigations, and hands-on learning. These activities would be possible and appropriate if the connections of mathematics and science were not explored in the lesson, but the use of such connections does not impede these practices, particularly in mathematics classrooms.

This finding also demonstrates mathematics teachers’ familiarity with practices typically associated with science to teach mathematics. It also exposes similarities in “good” science teaching and “good” mathematics teaching. Both disciplines support teaching that is grounded in students’ past learning experiences and focused on the development of a deep understanding of these disciplines by students rather than strict memorization of facts and procedures. In mathematics and science classrooms alike, learning and implementation of procedures can be enhanced with activities that enable students to understand algorithms and procedures, rather than merely learning a sequence of steps that lead to an answer.

Content connections observed in this study support the findings by Meyer, Stinson, Harkness, and Stallworth (2010) who found that teachers frequently focused on content or context in the teaching scenarios involving integration. This study supplements the findings of Stinson, Harkness, Meyer, and Stallworth (2009) and Meyer et al. (2010) by suggesting that content, process, and methods integration is observed in the lessons taught by mathematics and science teachers. Unlike teachers in a study conducted by Huntley (1999), whose practices frequently reflected “a directive or modeling mode of
instruction” (p. 65), mathematics teachers in this study embraced the use of hands-on learning and exploratory activities in their teaching of mathematics.

Mathematics teachers’ use of science processes and methods demonstrated their confidence in the positive effect of “good” science methods on their students’ learning experiences in mathematics. In the post-study interview, Maria supported learning through inquiry and discovery and emphasized the meaning of these types of experiences for her special education students when she commented:

But one thing that stayed constant from my lowest level learners to my highest is the discovery and their own data collection that they were doing, whereas traditionally in the past, I’d give, ‘Here you go; here is data,’ which really meant nothing to them. It was a bunch of numbers and this was, they made it their own and I think that really grabbed my disability students and held my honors students … I wanted hands-on lessons that … would be discovery-based.

Similar to Maria, Molly supported interactive learning when she said, “In math, it [the lesson goal for mathematics] was to have a hands-on experience, like a real world example of profit, like what, how do you calculate profit … to do it in a fun way that I thought would help them understand the concept better.” This suggests that typical mathematics lessons may not involve learning through scientific inquiry or discovery, but that teachers support these practices. By connecting mathematics and science, mathematics teachers may be inclined to introduce inquiry and discovery into their lessons and to teach in a way that benefits their students.
In this study, teachers viewed the use of scientific methodology (e.g., the focus on scientific inquiry and discovery) to teach mathematics as being appropriate and beneficial for all the students, not merely the honors students. In interviews, science teachers supported the idea that mathematics teachers could use scientific inquiry methods to teach mathematics content. Interestingly, in their own classrooms, science teachers did not use science processes and teaching methods to teach mathematics content as often as science, even when their lessons involved mathematics content and science processes and teaching methods. Because scientific inquiry continues to characterize “good” science teaching, the focus on sense-making and explorations, rather than rote memorization, could have a positive effect on the development of understanding of mathematics content. With respect to the teaching of mathematics, science teachers provided students with some opportunities to inquire about procedures, rather than to merely memorize them without asking why or how they work.

One interpretation of the use of *discovery, inquiry*, and hands-on learning in this study, particularly by mathematics teachers, is that the lessons reflected the nature of interdisciplinary activities that these teachers experienced in the GK-12 program. This inference is based on the research by Austin, Converse, Sass, and Tomlins (1992) and Batista and Mathews (2002), who suggested that professional development experiences could support teachers’ classroom practices related to integration. Thus, it is possible that the variety of interactive activities observed in teachers’ classrooms reflected the focus of professional development sessions. In their focus on mathematics and science integration, these professional development experiences offered opportunities for highly
engaging and interactive learning. This finding suggests that teachers called upon their experiences in the professional development in teaching lessons that connected mathematics and science. Although the purpose of this study was not to examine the impact of this program on teachers, data supported this conclusion.

**Extent of Integration of Mathematics and Science**

**Grade appropriate learning objectives.** Another finding of this study was that the grade appropriateness of the learning objectives—how well the lessons’ learning objectives aligned with the district curricula in mathematics and science—could play a decisive role in determining the extent of integration in the lessons, when this type of alignment was perceived as evidence of integration. The use of grade appropriate topics in mathematics and science classrooms could potentially lead to greater knowledge gains for students, if similar topics were studied in mathematics and science classrooms. This practice could also lead to greater collaborative efforts and improved interactions among teachers across disciplines, and result in an exchange of ideas related to effective teaching practices in other disciplines.

The literature emphasizes the need for the grade appropriateness of concepts in both disciplines as being desirable for integration (e.g., Davison, Miller, and Metheny, 1995; Lonning and De Franco, 1997). However, when mathematics teachers practiced mathematics and science connections, this condition was no reflected in their lesson choices. It was, however, reflected in lessons taught by the science teachers, who used students’ mathematical skills and knowledge to teach science. Most lessons taught by mathematics teachers lacked direct alignment with the district science curriculum, and,
consequently, focused on concepts in life science rather than physical or earth science. Only two lessons were selected based on their connection to the district curriculum in science. In contrast, lessons taught by science teachers were aligned with mathematics and science curricula.

One reason for this difference is the sequencing of mathematics and science that typically occurs in science curricula, allowing science teachers to focus on the teaching of science while using the mathematical skills acquired by students in mathematics classes. This finding suggests the possibility of a shortage of grade appropriate connections to science in the mathematics curriculum and the lack of daily experiences with grade appropriate connections in mathematics classrooms. The lack of such connections was observed in mathematics classrooms when teachers not only presented lessons that were desynchronized with the science curriculum, but also taught these lessons for the first time and for the purpose of this study. In contrast, most lessons taught by the science teachers were not new lessons.

What this study suggests is that whereas the district science curriculum provided science teachers with a variety of curricular connections with mathematics, mathematics teachers needed to find lessons involving these types of connections. They typically did not consult their district’s science curriculum. They also did not use lessons from their existing repertoire of mathematics lessons. They sought and adapted new lessons using the Internet and other resources. The lack of alignment of the science content with the district science curriculum in most lessons was not a concern for these teachers since their lessons typically met other criteria, including student interest or process/methods
integration. Furthermore, most lessons taught in mathematics classrooms presented new science material, and these lessons did not rely on the students’ prior knowledge of science content but presented content rich in scientific knowledge.

Because the science curriculum in this study correlated topics with the students’ mathematical skills and abilities, the teaching of mathematics and science connections required more planning and preparation from mathematics teachers than science teachers. In addition, teachers’ prior experiences with interdisciplinary connections were generally more common in science than mathematics classrooms. Thus, science teachers’ lessons involved grade appropriate topics not only because teachers chose to teach such topics, but also because these topics were already part of their ongoing science curriculum. Similar correlations of curricular topics were not as common in the mathematics curriculum, requiring mathematics teachers to seek lesson plans outside of their typical repertoire of lessons. This finding suggests that the mathematics teachers’ experiences with mathematics and science connections could be improved with increased accessibility to and support with integrated curricular materials and the equipment needed for successful integration of science into mathematics.

**Balance of learning objectives.** This study found that lessons that connected mathematics and science varied in the extent to which they represented integration, with most lessons lacking the equality of balance in instructional focus on grade appropriate mathematics and science learning objectives. Although there are many possible reasons why this occurred, this study shows that teachers’ perceptions of integration and connections are relevant to their practices and could affect how well mathematics and
science are connected in the classroom. The extent of integration in the observed lessons may have been different in this study if teachers perceived the teaching of mathematics and science connections as indicative of integrated instruction, believing that integration required equality of focus on learning in two disciplines, or if they thought that the balance of mathematics and science objectives was necessary in every lesson involving the connections of mathematics and science. Thus, if teachers find the balance between mathematics and science objectives as desirable or necessary in a lesson, then the lesson is more likely to be balanced.

The aforementioned requirements for integration were difficult to meet when teachers used mathematics to teach science or when science was used as a context in which to deliver mathematics. In both cases, the focus on “using” concepts from one discipline to teach new concepts in another discipline, without the necessity to teach both concepts, resulted in unbalanced lessons. For instance, five of eight lessons taught by the science teachers lacked equality of focus on the learning goals in science as well as mathematics. Science teachers frequently used mathematics to teach science. Similarly, many mathematical teachers’ lessons, for whom connecting represented one discipline being used to teach another, were not grade appropriate, despite some lessons being balanced. This finding reveals that by connecting mathematics and science, teachers can balance mathematics and science, but these connections may not occur when instruction is dominated by one discipline or when the goal is a seamless blending of these subjects.

By focusing on the assessment of the extent of integration in lessons involving mathematics and science connections, this study adds to the research of Huntley (1999)
who focused on the integrated practices of middle school teachers and found “no activities in which the goal was learning new material from both mathematics and science” (p. 64). This study found evidence of grade appropriate integration in two lessons, and a balance of content in mathematics and science (not necessarily grade appropriate) was identified in four more lessons. This study also found lessons with interdisciplinary connections representative of “mathematics and science” (Huntley, 1998, 1999). This result suggests that teachers in this study engaged in integrated instruction when connecting mathematics and science, and that some of these connections were balanced and grade appropriate. Thus, the focus on teaching concepts that connect mathematics and science might result in balanced lessons.

In this study, teachers were not given a definition of integration; they were merely asked to connect mathematics and science. In the study by Huntley (1999), the definition of integration was shared with teachers. This definition required teachers to “dissolve the disciplinary boundaries between mathematics and science” (p. 60). It is possible that the extent of integration in this study would have been different had the teachers shared a common goal for these lessons (i.e., integration), and did so with appropriate support in professional development sessions. Collectively, the findings of this study and Huntley (1999) suggest that successful integration requires more than a common definition and that the pursuit of seamlessness may not always result in genuinely integrated practices.

**Integrated Instruction**

The successful integration of mathematics and science requires the knowledge of the district curricula, content, and pedagogy in both disciplines. It is critically important
that the lessons connecting or integrating mathematics and science do not compromise
the rigor or the integrity of these disciplines. The findings of this study suggest that
mathematics and science teachers support mathematics and science connections in their
classrooms, but need additional support with the design and implementation of such
activities. This support is related to the three aforementioned conditions for successful
integration.

In this study, teachers taught lessons that were appropriate for their students in
content and pedagogy, particularly for concepts in the teachers’ instructional disciplines.
However, teachers reported lacking the knowledge of each other’s curricular standards.
In the case of the science teachers, they typically used mathematical procedures and skills
known to their students to teach science, as opposed to applying “good” science and/or
mathematics teaching methodology to teach mathematics. Mathematics teachers, on the
other hand, taught new material in science and mathematics. However, they typically
presented topics that were not part of the science curriculum, rather than built upon their
students’ existing knowledge of science. Mathematics teachers implemented science
content, processes, and methodology, and connections with mathematics were perceived
as appropriate for all students, including students with disabilities. However, the science
content was not always related to the science curriculum, and as was stated earlier, this
alignment could have potentially been grade appropriate had the teachers adhered to the
district science curriculum.

In this study, mathematics and science teachers perceived integration as
beneficial, active, good, changing, and expanding. At the same time, mathematics
teachers lacked confidence in their ability to integrate instruction. This result indicates that, while mathematics teachers may support integration, they sometimes refrain from integrating science content into mathematics in their day-to-day activities due to the lack of confidence in their ability to teach science content. This study suggests that the lack of confidence in the knowledge of science content among mathematics teachers was related to the limited extent to which these teachers engaged in integrated instruction before the study, and, perhaps, a limited, if any, pre-service education coursework geared toward such activities.

By focusing on the middle school teachers, this finding complements the research of Lehman (1994), who studied elementary school teachers’ perceptions of integration and also found teachers to be generally supportive of integration. Like their colleagues, the middle school teachers in this study supported integrated instruction. They also stated that integration was not a common teaching practice in their school setting and that hands-on activities were not more appropriate for science than mathematics. However, mathematics teachers in this study perceived their background knowledge in science as being insufficient for authentic integration. Despite being able to use their own lessons, science teachers also reported lacking awareness of additional curricular materials for integration. This finding suggests that teachers need more support in their efforts to integrate their courses and that this support is needed in both science and mathematics.

This study also supports the findings of Weiss, Banilower, McMahon, & Smith (2001) whose survey results suggested that teachers lacked familiarity with content standards in science (NRC, 1996) and mathematics (NCTM, 2000) in their subject
matter. In this study, teachers reported lacking familiarity with the curricular standards in the discipline they were connecting to their primary discipline. Thus, if integrated instruction requires an equality of focus on mathematics and science objectives in a lesson, then this survey and this study emphasized the need for teachers to strengthen their familiarity with standards in both science and mathematics.

If integrated instruction is perceived as an opportunity to teach mathematics and science, with an equal focus on both disciplines in the lesson, then teachers need to become more familiar with the district curricula as well as state and national standards. Lessons extending beyond the intended school curricula could provide students with rich learning opportunities supported by teachers and districts, but it is also important for some integrated lessons to meet the goals of the school curricula in each subject. This strategy would enable teachers to provide students with meaningful opportunities to deepen their knowledge of science and mathematics in well-focused contexts. However, without understanding the intended goals and objectives in each discipline and not adhering to these goals and objectives in planning and teaching, the instructional practices involving connections could fall short of meeting their full potential for student learning. As a result, such lessons would not be perceived as “balanced mathematics and science” and would not be situated in the middle of the continuum of integration (Lonning and De Franco, 1997).

Meyer et al. (2010) stated that, “For most of the teachers, standards were viewed negatively and as a hindrance to what they wanted to do as teachers (…) The standards and the testing of the standards has reorganized the instruction in each of the schools and
changed the teaching priorities” (p. 163). Therefore, it seems plausible to suggest that the lack of focus on integrated teaching and learning in the state or national standards, or the district content standards, particularly in mathematics, may dissuade teachers from integrating instruction. If integration is not perceived as relevant to or desirable for student learning of mathematics and science, then the concept of integration may be supported by teachers but not practiced.

Teachers need to constantly adapt their classroom practices to address the needs of students, the curriculum, and their own beliefs and perceptions of effective teaching. Because this study demonstrates that teachers make decisions that reflect these factors, it supplements the findings of Stinson, Harkness, Meyer, and Stallworth (2009), who suggested that “in the absence of clear characterizations or parameters for what constitutes integration, teachers apply their own criteria based upon their knowledge and beliefs” (p. 159). Frykholm and Glasson (2005) reinforced this view, stating, “In what may be a more realistic and hopeful approach [to integration], therefore, we advocate the use of terminology that includes the notion of connections between science and mathematics – connections situated in the respective practices of each field and in the common experiences of learners” (p. 130). This study reveals that mathematics and science connections could lead to lessons in which both disciplines are perceived by teachers as equally important, and that these lessons could occur with the support of professional development in integrated and interdisciplinary instruction.

This study suggests that both mathematics and science teachers would benefit from continued professional development aimed at the specific needs of each group,
mathematics and science. With an increased access to integrated and interdisciplinary lessons, including supplementary materials in science content for mathematics teachers and mathematics pedagogy for science teachers, the quality of the integrated instruction could be strengthened in mathematics and science classrooms. For science teachers, these materials could be enhanced with activities focusing on the teaching of mathematics, rather than the applications of mathematical skills and procedures in scientific contexts. In a similar way, materials intended for mathematics teachers could focus on grade appropriate activities, enhanced with detailed descriptions of related science content. This marriage of interests could result in more productive learning in both disciplines.

**Limitations of the Study**

As part of the GK-12 program, this study shares the general components of the program’s structure, design, and goals for middle school teachers. For instance, the researcher did not control the selection of the study participants or the program’s primary goals and objectives. The general format and content of teacher and Fellow contracts and consent and assent forms were also those of the GK-12 program. As a result, the study participants were selected for the program by their district; thus, the study utilized a convenience sample.

Furthermore, as the program manager from September, 2007 to June, 2013, the researcher had developed substantial knowledge of and familiarity with the program and the participating districts. This position precluded the researcher from functioning as a complete outsider to the school district and the participating school. For instance, from September 2007 to May, 2012, the researcher assisted program directors with the design
and implementation of pedagogical activities. However, the researcher was not involved in research-related activities in the program prior to the study. Such research activities were directed by a team of faculty members with specialties in qualitative and quantitative research methods.

The findings of this qualitative study reflected the practices, perceptions, and attitudes of four middle school mathematics and science teachers about connected and integrated instruction. The small sample size and the qualitative nature of the study preclude the generalizability of these findings for teachers and classrooms in other grade levels and disciplines. Therefore, the study’s findings are most relevant to mathematics and science teachers working in similar educational settings (i.e., visiting scientist programs, professional development in integrated instruction).

Teachers participated in professional development activities with the researcher. These activities focused on integrated and interdisciplinary instruction, which may have altered teachers’ understanding of integration. However, these workshops were developed as opportunities for teachers to work together, to examine integration and integrated teaching, and to exchange ideas about integration. The researcher did not attempt to impose specific definitions or descriptions of integration in these workshops.

**Missing Data**

The researcher completed all scheduled interviews and lesson observations. Each teacher in the study was observed teaching four lessons in mathematics and science connections and participated in six semi-structured interviews. Some missing data were identified in the course of the study, but the number of such items was low. These items
included artifacts collected as part of monthly workshops and lesson observations as well as selected items on the survey.

For instance, during one workshop, science teachers chose not to submit their work. It is important to note that the focus of this workshop was mathematics (Lonning & De Franco, 1997), with limited, if any, explicit connection made to science. In addition, one teacher did not complete a workshop (and all related activities) due to a work-related commitment. For the surveys, three teachers resubmitted incomplete pages from pre- and post-program surveys. These teachers explained that the missing pages were omitted accidentally, and they submitted them later either in person or by mail. One teacher left a blank page on the post-program survey and did not resubmit it as requested.

In addition, teachers agreed to provide copies of their lesson plans, lesson materials, and sample student work for all their lessons; these items were later shared with the researcher. Four lesson plans were submitted in the form of student handouts with a description of lesson objectives and directions for lesson activities. Teachers submitted examples of student work, but only for selected lessons. However, the researcher had the opportunity to review student work in subsequent classroom visits.

**Implications of the Study**

The findings of this study are intended for educational researchers, professional development leaders, classroom science and mathematics teachers, and school districts.

**For Research**

Analogous to the arguments about the need for additional studies in integration presented in the literature (e.g., Frykholm & Glasson, 2005; Judson, 2013; Pang & Good,
2000), this study reinforces the need for continued research concerning teacher practices related to mathematics and science connections and integration. In particular, future studies should focus on the connections of science content and mathematics content, and mathematics pedagogy and science content. This study explored the connections of mathematics content and science content, processes, and teaching methodology, and showed that content connections were most common, although mathematics teachers typically did not align such content with the district standards. Mathematics teachers in this study also taught mathematics using scientific processes and methods. This study did not focus on the integration of mathematical processes or methods with science content. In the absence of studies focusing on teacher practices, future research should focus on the role that the teaching of science content has on the teaching of mathematics content and how science content influences teaching and pedagogy in mathematics.

In the era of *Next Generation Science Standards* (NGSS Lead States, 2013) and *Common Core State Standards for Mathematics* (CCSSI, 2010), it is important to continue to learn about the connections between “good” mathematics and science teaching methods, including research on how, if in fact, “good” mathematics teaching affects instruction in science classrooms. Such studies would inform teacher practices in both disciplines. Furthermore, it is important to study the impact that these new science and mathematics standards will have on integrated instruction. This study was conducted prior to the implementation of *Common Core State Standards* in the district. One teacher in this study considered the connections between mathematics content, science processes and methodology to be appropriate for the *Common Core State Standards*. It is essential
to continue to study how the mathematics and science content and practices embedded in these documents will affect future integration efforts in these disciplines.

In the absence of a definition of integration, this study emphasizes the need for instruments that can accurately assess the extent of integration of mathematics and science in the classroom. The development of future instruments could be informed by the theoretical framework that guided the data analysis in this study. The criteria for integrated instruction in these instruments could serve as a source of information about integration for teachers, administrators, and educators. Judson (2013) recently presented such an instrument, which was designed to assess mathematics integration in student-centered science. Similar instruments are needed for future assessment of science content and process integration into mathematics.

For Professional Development

In this study, teachers either reported that they lacked awareness of curricular materials that were appropriate to their settings or searched for new materials for integration. Leaders of professional development programs can support mathematics and science teachers in their efforts to connect mathematics and science in the classroom by providing them with appropriate materials for integrated instruction. These materials could also be developed by the teachers. Professional opportunities for teachers to work collaboratively and develop activities, projects, and/or curricula could result in grade appropriate materials, aligned with school district curricula as well as state and national standards, in addition to other equally-appropriate resources.
This study showed that mathematics teachers lacked classroom and professional experiences with science integration into mathematics compared to science teachers. Thus, it is important that professional development activities not only present teachers with materials for integration, but that teachers have the opportunity to experience these materials in practice. These opportunities might involve mini-lessons conducted during workshops or in the classroom. In both cases, professional development leaders need the expertise in implementing integrated materials in the classroom.

Thus, it is important that the education community continues to develop materials for integrated mathematics and science teaching and share these materials with teachers. The findings of this study suggest that these materials include but not be limited to: 1) descriptions and examples of mathematical practices and “good” mathematics teaching methodology for science teachers; 2) descriptions of science content for mathematics teachers, and 3) curricular standards in science and mathematics for teachers in both disciplines.

As suggested by Austin, Converse, Sass, and Tomlin (1992) and Basista and Matthews (2002), teachers who participate in professional development activities that focus on integrated instruction of mathematics and science can develop stronger content knowledge and pedagogical content knowledge for integration. In this study, teachers were generally supportive of integrated instruction in mathematics and science, although they lacked confidence in their ability to integrate these subjects. As participants in the GK-12 program, they were encouraged and supported in their efforts to connect these two disciplines; however, such connections might not have occurred without the support of
the program, particularly in mathematics classrooms. Mathematics teachers first adapted lessons that connected mathematics and science and then invited the researcher to their classroom. Despite not being able to draw upon some of their old lessons, these teachers delivered new lessons that connected mathematics content with science.

**For Teachers**

Findings from this research have implications for teachers with respect to learning objectives in integrated lessons, the use science process and methods connections, and the role of collaborative work in the design and implementation of lessons with mathematics and science connections. First, science teachers in this study typically perceived their lessons as being connected when skills and/or procedures in mathematics were “used” to teach science. Mathematics teachers used science as a context to make mathematics topics more interesting for students. However, not every lesson in which one discipline was used to teach the other involved a similar focus on the learning objectives in both disciplines. For example, in science classrooms, students applied mathematical skills and procedures to new science contexts, but the focus of instruction was not on the teaching of mathematics. For instance, students used their knowledge of least-common multiples to balance ionic compounds, but they did not explore or examine the concept of least-common multiples. This lesson connected mathematics and science content but lacked the equality of focus on learning in both disciplines. In mathematics classrooms, new material in science was presented, but many lessons were not aligned with the district science curriculum.
When teaching mathematics and science, teachers can deliver lessons that connect these disciplines as well as integrate, with integrated lessons having the potential to meet curricular objectives in two subjects. This teaching strategy could positively affect student learning in both subjects. However, this type of integration requires teachers to use content aligned with the district curricula in both subjects; this study showed that such alignment does not always happen when mathematics and science are connected in the classroom. The focus on the selection of lessons aligned with each curriculum may be especially important in mathematics classrooms since most lessons taught by mathematics teachers in this study were not directly aligned with the district science curriculum. Science teachers, on the other hand, generally used appropriate content in mathematics but their lessons were not balanced in terms of instructional focus on learning in each discipline. What this finding suggests is that integrated instruction could not only connect two disciplines, but also result in knowledge gains in both subjects.

The extent of integration in lessons connecting mathematics and science can vary, depending on the extent of the focus on grade appropriate lesson objectives (alignment with the district science and mathematics curricula) in the lessons. Thus, it is important that teachers adhere to district curricula for guidelines regarding topics for instruction at the given grade level, which allows students to recognize similarities in topics presented in each classroom, and possibly build upon their existing knowledge in both subject areas. Using integrated instruction, teachers could also support each other’s teaching efforts in the classroom.
Second, teachers often lack confidence in their ability to integrate these subjects, particularly when they perceive their content knowledge in science or mathematics as being insufficient. One possible solution to this problem is encouraging participation in professional development workshops that focus specifically on science and mathematics content integration. Another solution lies in connecting mathematics content and science processes and methods. These connections could be based on experiments, investigations, inquiry, and discovery—activities that involve “good” mathematics and science teaching. Thus, such connections might already be familiar to mathematics teachers. Science teachers could also use such connections to teach science and mathematics. When teaching mathematics using “good” science methods, science teachers support the work of their colleagues by enabling students to think about and with mathematics in science classrooms.

It is always important that lessons support the needs of students. Science teachers can achieve this goal by remaining sensitive to their students’ background knowledge in mathematics and by expanding this knowledge through activities that develop deeper connections rather than merely procedural knowledge. In mathematics classrooms, on the other hand, Maria and Molly taught lessons that included science content, processes, and methodology connections and perceived these lessons as being beneficial for their special education students as well as their honor students. According to the teachers, science connections provided students with interesting, more authentic and meaningful contexts for mathematics learning and engaged them in hands-on, inquiry- and discovery-based activities.
Finally, teachers can practice mathematics and science integration in collaborative teams. In the study, mathematics-science teams of teachers and visiting scientists engaged in an exchange of professional experiences and knowledge of students, methods, curriculum, and content throughout the school year. These collaborative teams were important for this study because they provided teachers with the opportunity to grow in their professional expertise within the context of their classrooms. For example, in this study, one team (two teachers) delivered a lesson including learning objectives in both disciplines. By co-teaching this lesson, teachers were able to address the key goals of the lesson in mathematics and science, while supporting each other in the delivery of the lesson. Such collaborations are desirable for implementing integration in education, because they enable teachers to learn from each other, while remaining experts in their primary subject areas.

**For Districts**

School districts can encourage teachers to implement integrated or interdisciplinary instruction by providing them with opportunities for collaborative work across disciplines, emphasizing science and mathematics integration or connections in the district curriculum, as well as providing time during the academic year for integrated experiences for students and teachers through science and mathematics fairs, visiting scientists, science and mathematics field trips. Weiss, Banilower, McMahon, and Smith (2001), who studied mathematics and science teachers’ perceptions about their preparedness for teaching, point to the lack of free time during the school day to
collaborate with other instructors. This, in turn, can hamper teachers’ ability to formulate lessons or consult with their colleagues about issues related to content and pedagogy.

Roebuck and Warden (1998) suggested, “If mathematics and science teachers are to apply the notion of true integration of content, they must work together to plan and implement such lessons” (p. 332). Teachers in this study were very enthusiastic about collaborative work. All of the teachers supported collaborations that focused on mathematics and science integration. Their support was expressed both on surveys and in interviews. In addition, one of the teachers, Steve, suggested that mathematics and science curricula could be paced, sequenced, and presented to the teachers as a way to promote integrated instruction in the district. He suggested:

If the calendars could be created simultaneously with the math and science, instead of the departments doing it separately, I think that would help force that type of connection, and then when it does come up when someone goes to a workshop or somebody comes back and gets inspired, ‘Oh, we have to do this,’ it will be much easier for them to actually implement it now because the schedule and the structure is already in place and all they have to do is be motivated, whereas we could be motivated now, but all of the sudden Maria only has one 7th grade class or she’s only teaching 8th grade next year, and it might not work as easily.

This study incorporated monthly professional development workshops and weekly classroom support of integrated teaching by the mathematics-science teams of visiting scientists. In the process of working with each other and visiting scientists,
teachers in this study had the opportunity to institute changes in their daily teaching methodology for their science and mathematics classes. Moreover, although mathematics teachers lacked confidence in their ability to integrate science into their classes, in the end, they expressed satisfaction at being able to introduce science into their classrooms, perhaps for the first time in their professional careers.

Nevertheless, the genuine integration of mathematics and science requires more than the mere intention to integrate. It is critical for teachers to be knowledgeable about mathematics and science content, processes, and pedagogy, and to have access to a wide range of materials in the field of mathematics and science integration. Lacking these elements, teachers may revert to their traditional practices and continue teach mathematics and science separately. However, if provided with opportunities to learn and think about connections and integration, with their district support, teachers will engage in classroom practices that reflect meaningful connections between mathematics and science.

Aside from professional development and improved administrative support of integration for in-service teachers, it has been demonstrated that mathematics and science integration is strongly supported by pre-service teachers when they are able to engage in activities related to integration in their undergraduate courses (e.g., Berlin & White, 2012; Frykholm & Glasson, 2005; Koirala & Bowman, 2003), but that the perceptions and attitudes regarding the feasibility of integrated instruction change when these novice teachers begin their field work (Berlin & White, 2012). Their concerns are typically related to the issues of inefficiency and difficulty with science, technology, engineering,
and mathematics (STEM) integration. This finding suggests a possible disconnect between pre- and in-service experiences of teachers with respect to integration. If integration is desirable in K-12 classrooms, then the issues of infeasibility and difficulty with integration need attention from the education community.

**Recommendations**

Additional research on teacher practices is essential if the education community -- teachers, teacher trainers, administrators and policy makers -- is to continue to expand its understanding of the importance of integrated mathematics and science instruction. Future research efforts should also attempt to clarify *what it means* to integrate science and mathematics as well as *how such integration can be achieved*. The researcher recommends that future research continue to focus on the development of instruments for assessing the integration of mathematics and science in a variety of educational settings.

This study revealed that middle school mathematics and science teachers were able to connect mathematics and science with the intended equality of instructional focus toward each discipline. This finding was significant because it demonstrated that connections and integration could be foreseen as related concepts and that the integration of mathematics and science could be achieved in lessons that connected these disciplines. However, without a set of clearly defined guidelines and definitions, future attempts to assess teacher efforts to connect mathematics and science will be challenging.

Moreover, future programs like the GK-12 program could provide opportunities for continued professional collaborations between educators, scientists, and practitioners. Such programs enable teachers to strengthen their content knowledge as well as their
pedagogical knowledge of mathematics and science (e.g., Mitchell et al., 2003; Beamer, Van Sickle, Harrison, and Temple, 2008). Both goals were found to be relevant to the success of mathematics and science integration in this study.

Activities that enable teachers to work together with visiting scientists, educators, and colleagues may be inadequate to enable teachers to engage in integrated instruction, unless this form of instruction is supported by the state and national standards and reflected in school district curricula. It is recommended that members of the education community continue to support mathematics and science teachers in their efforts to make meaning of science and mathematics teaching and learning.
References


Common Core State Standards Initiative.(2010).*Common core state standards for mathematics*. Washington, DC: National Governors Association Center for Best


Kolebas, P. (1971). The effects on the intelligence, reading, mathematics, and interest in science levels of third grade students who have participated in science-a process approach since first entering school. (Doctoral dissertation, University of Virginia, 1971). *Dissertation Abstracts International, 32*(08), 4443A.


presented at the NSF/SSMA Wingspread Conference, Racine, WI.


Appendix A

Teacher Contract

NSF GK-12 Fellows in the Middle 2012-2013

Teamwork, collaboration and communication among all participants, including teachers, Fellows, research mentors, and project personnel are vital to the success of the GK-12 program. We expect that the grant will provide many benefits and opportunities for both you and your students.

Your base stipend for participating in the program is $2000. As noted in the contract below, your participation in various aspects of the program can increase this amount by $100. You will be paid up to $1000 on or near the following dates: 10/30/12, 2/28/13, and 6/30/13.

Teachers are expected to participate in the activities that follow.

1.) In the schools:
   - Be the primary party responsible for all management, instruction, and activities in the classroom and on all field trips. The resident scientist or mathematician (Fellow) will work in your school for 5 hours each week, on one regularly scheduled day, to support classroom activities and student learning. Additionally, away from the middle school, they may spend up to 5 hours per week researching and preparing educational materials. Please let us know if your Fellow is not meeting these time commitments. For the first month, Fellows will mainly be observers. As they become more comfortable with the setting, they will be asked to increase their participation, ultimately as co-teachers in the classroom. We have found that science/math Fellows co-teaching works best. If at all possible, we would encourage this model of implementation.
   - Meet with the team. Common planning times with both partner teachers and both Fellows participating is crucial. We expect that teams of Fellows and teachers meet weekly to reflect, plan, and assess student learning.
   - Whenever possible, give priority to lessons developed or co-developed by the Fellows.
   - Let the Fellows know ahead of time if there needs to be a change to the weekly schedule.
   - Be in the classroom at all times during class. The Fellows are not allowed to be left in the classroom with the students without a teacher or substitute teacher present.
   - Participate in grant-related activities including selected Summer Institute activities, field trips, professional development activities, assessment activities, and meetings. We will provide you with a calendar of events.
• Contribute to the development of curriculum units and implementation of the unit. Reinforce the material presented in these units and do follow-up lessons and reviews.

• Provide the Fellows with constructive feedback on their lesson presentation in the classroom and overall communication with the middle school students.

• The Fellows are not student teachers; they are graduate students in a research field. Their primary objective through this program is to improve their overall communication skills and to contribute to middle school classrooms by sharing their knowledge of current science and mathematics research. This objective should be kept in mind throughout the year.

2.) Assessment:
• Be part of our programmatic assessment efforts:
  o participate in interviews with the research team throughout the program
  o complete content and attitudinal surveys
  o provide samples of grant-related instructional materials (lesson plans, unit plans, student worksheets, etc.)
  o participate in NSF assessments up to twice a year--at least once each for the GK12 program report and for the GK12 nationwide assessment.
  o Allow visits by project personnel and district liaisons to assess how the program is being implemented in your school, including possible videotaping of your lessons.
  o Participate in other informal assessment including observations of Fellows and students and possible videotaping of these observations.
  o Assist with assessment of Fellows and your middle school students. Assist in all assessment activities including administration of surveys, distributing and collecting parental consent and student assent forms, turning in lesson plans when requested, and communicating with parents if they have questions.
  o cooperate with the qualitative research team in scheduling classroom observations. (Fellows and teachers will be videotaped during these observations.)
  o Collect items from students to be put into student portfolios. Some of these portfolios will be collected periodically.

3.) Professional Development
• Summer Institute
  o Attend a GK12 overview information session for teachers, Fellows, and research advisors on Thursday, May 10, 2012 from 9am – 3pm, Sokol room, Science Hall
  o Attend a professional development workshop on Populations and Ecosystems on Friday, May 18 from 9am—3pm, Science Hall 211
  o Allow Fellows, research advisors and project personnel to visit your classes for two hours on Tuesday, May 22, 2012, time to be agreed upon.
- Attend all-day fieldtrip training at New Jersey School of Conservation on Monday, June 4, 2012 from 9am—3pm
- Monthly Workshops during the school year
  - Participate in professional development workshops from 3—4:30pm (at the XXX School) on the following Thursdays:
    - September 20
    - October 25
    - November 29
    - And one in December, if necessary
    (The spring semester schedule will be set late in the fall.)
  - Meet with team (mathematics teacher, science teacher, science Fellow, mathematics Fellow) at regularly scheduled times for one hour per week to reflect upon the past week and to engage in short- and long-term planning. MSU research advisors join the team meetings some months. Regularly meet with your Fellow to reflect on the previous week’s activities and to plan for the next week or two. We have found that both of these planning meetings are key components to the successful and smooth integration of GK-12 activities into the educational experiences of your students.
  - Be responsible for obtaining professional development credit or other career-advancement incentives from your school district for your participation in the program.

4.) Project-related
- Communicate with project personnel on a regular basis.
- Address Fellows as “Mr. _____” or “Ms. _____” in the classroom and refer to them as resident scientists or mathematicians.
- Provide at least a rough curriculum guide for the entire year. (Bring with you May 10.)
- Compensation will be offered under the following structure:
  - $2000 for completing all school-based activities (including assessments and regularly providing written and spoken feedback to the Fellows about their lesson plans and presentations) during the school year.

Additionally:
- $500 for attending all monthly workshops during the school year.
- $100 for critiquing Fellows’ unit plans over the summer
- $300 for participating in the entire Summer Institute.
- $100 for presenting on GK-12 related activities at a regional or national conference of a professional organization.

(Compensation will be pro-rated for partial completion of activities.)

Please sign below to indicate that you are committing to participating in the 2012-2013 Fellows in the Middle program and that you agree to the above list of expectations. Please return this completed form to Eliza Leszczynski by April 27, 2012:
Eliza Leszczyński
Department of Mathematical Sciences
Richardson Hall, 1 Normal Avenue
Montclair State University
Montclair, NJ 07043
leszcynskie@mail.montclair.edu
fax (973) 655-7686

Signature: _______________________
Date: _______________________
Name: _______________________

Home Address: _______________________

Phone number: _______________________
Cell phone number: _______________________
Email: _______________________

Subject(s) you teach: _______________________
School Name: _______________________


Appendix B

District contract

NSF GK-12 Fellows in the Middle

School and District Agreement
2012-2013

The National Science Foundation GK12 Fellows in the Middle program at MSU pairs mathematics and science research graduate students (Fellows) with middle school teachers. For AY2012-2013, the program will be working with XXX School, XXX School District. The program will support two mathematics and two science Fellows, paired with two mathematics and two science teachers. To promote interdisciplinary instruction and learning, mathematics and science Fellows will co-teach all lessons.

Recruitment/Summer Activities

- District administrators will identify a pool of grades 6-8 mathematics teachers and science teachers as potential participants in the grant project. Those teachers are expected to have good communication and classroom management skills. Together, we will choose the strongest pair(s) of candidates.

- Once a pair of Partner Teachers is selected, we strongly encourage the school to maximize their common prep periods and the number of students that both of them instruct. Participating students are those that are taught by both Partner Teachers. The grant provides support for all participating students to attend two field trips—one to the School of Conservation (Monday, October 15 and Tuesday, October 16 [up to 100 participating students each day] and Friday, June 7 for Math/Science Day at MSU.) Additional students may be accommodated if space is available, but they would be supported by the district.

- On Tuesday, May 22nd, 2012, allow the GK-12 Fellows, their university advisors and/or grant personnel to visit the school to meet the teachers and staff and familiarize themselves with the school environment. This will involve up to 10 visitors for about 2 hours.

- Provide release time for teachers during the Summer Institute in May/June 2012 to:
  - Attend an introductory seminar and workshop for teachers, Fellows, and research advisors on Thursday, May 10 from 9am—3pm.
  - Attend a professional development workshop on Populations and Ecosystems on Friday, May 18 from 9am—3pm
  - Attend all-day fieldtrip training at the School of Conservation on Monday, June 4 from 8am—3:30pm.

- If necessary, provide support for teachers during the academic year to
  - Participate in professional development workshops from 3—4:30pm (at the XXX School) on the following Thursdays:
    - September 20
- October 25
- November 29
- And one in December, if necessary
  (The spring semester schedule will be set late in the fall.)
  o Participate in professional conferences - see below

School and classroom activities – We expect districts to:
- Occasionally provide space for a small group (4 – 10 individuals) to meet for one or two hours either during or at the end of school day.
- Assist the Partner Teachers and their assigned GK-12 Fellows with routine classroom support. The goal is for the Partner Teachers and Fellows to be a school-based team. The teachers have classroom management, organization and communication skills. The Fellows will serve as a content resource to the teachers and students. Fellows will also help plan classroom and school based activities as well as field trips and connect current research in science and mathematics to the science and mathematics being studied.

Fieldtrips
- For field trips, the grant will cover the admission cost of Partner Teachers, necessary chaperones and participating students and the cost of bus transportation. Schools will make arrangements for permission slips, chaperones and substitute teachers and if school policy dictates, provide support for any non-participating students who go on a grant funded field trip.
  Participating students are those that are taught by both participating teachers. Students who are taught by only one (or none) of the Partner Teachers are considered non-participating. Fees including admissions and additional buses necessitated by inclusion of non-participating students will be the responsibility of the district.

Partner Teacher participation in conferences and collaborations - We expect districts to:
- Assist teachers by providing support to attend a regional or national conference to present GK-12 activities. Assistance can be in the form of providing time off from teaching, providing substitute teachers, and covering fees such as travel, lodging, per diem and registration.

Assessment of program – We expect districts to:
- Assist grant personnel and evaluators to conduct pre and post student and teacher surveys and achievement assessments if asked to. This includes the distribution and collection of both student assent and parental consent forms that we will provide. Whenever possible we plan to use the science and mathematics assessments (NJ ASK) currently used by each district. But for science we will also use a Terra Nova test for grades 6 and 7 and a released NJ GEPA for grade 8. Please be advised that members of our research team will visit each Fellow and teacher periodically to observe and possibly videotape a lesson. These visits will be arranged ahead of time by the research team and the teachers.
  Each participating teacher may be asked to complete pre and post content knowledge and attitude assessments, the results of which will not be shared with district administrators.
Please be advised that NSF may want all participating districts to use a (possibly different) uniform assessment for student achievement. All research protocols have been approved by MSU’s Institutional Review Board. Please note that all data will be coded and only the results of aggregate data will be used in our reports to NSF or in publications or presentations. No individual or school will be identified by name with any specific data items.

- Publicize program activities: Use public speaking engagements and other media opportunities to publicize program activities. Alert project directors to all mention of the program in newspapers, presentations, announcements, etc.
- Support the review and continuing implementation of curriculum units developed by the interdisciplinary teams (Fellow, teachers, research advisors, project staff).
- Provide appropriate professional development credit to teachers.

Please sign below to indicate that you are committing to participating in the 2012-2013 Fellows in the Middle program and that you agree to the above list of expectations. If you have any questions, comments or concerns, please let us know.

Please return this signed agreement to Mika Munakata by mail or fax (973) 655-7686 by Friday, April 27, 2012 and retain a copy for your records. If you have any questions, please contact Mika Munakata at (973) 655-7256 or munakatam@mail.montclair.edu.

Signature:____________________________________ Date:____________
Name:__________________________________________  Title/Position:____________
Phone number:____________________________________
Nominated mathematics teacher(s):____________________________
Nominated science teacher(s):____________________________
Appendix C

Professional Development Workshops

Listed below are descriptions of activities used in the monthly professional development workshops in this study. The descriptions are organized by date. The purpose of each workshop was to engage teachers in activities involving mathematics and science connections and integration. These activities were adapted from research studies on mathematics and science integration. Other activities were developed at the request of the study participants and aligned with the curricular needs of the school district.

I. Workshop #1: September 20, 2012
   Program-related administrative activities focusing on the upcoming fieldtrip to the New Jersey School of Conservation, Branchville, NJ.

II. Workshop #2: October 25, 2012  Theme: Continuum Model
   1) Introductory activity: Reflecting on our fieldtrip experiences
      This past week, you and your middle school 6th and 7th grade students visited the New Jersey School of Conservation in Branchville, NJ. On this field trip, you had the opportunity to participate in the following four activities at three different sites: Stream Sediment Carrying Power, Watershed Simulation, Stream Volume of Flow, and Sampling Stream Life Forms.
      a. In your opinion, were any of these four activities *interdisciplinary*? Write a brief explanation.
      b. Were any *math and science connections* embedded in these four activities? If yes, give at least one specific example. If no, explain why not.
      c. Did any of the four activities *integrate math and science*? Why do you think so? Give at least one example of integration, if it exists.

   2) Lesson example #1\(^1\):
      a. Teacher begins by asking students, “What are ratios?”
      b. Which of the following two recipes for guacamole are the same?

<table>
<thead>
<tr>
<th>Amount of guacamole</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>¼ cup</td>
<td>¼ cup</td>
<td>½ cup</td>
</tr>
<tr>
<td>The number of dashes of hot sauce</td>
<td>3 dashes</td>
<td>6 dashes</td>
<td>6 dashes</td>
</tr>
</tbody>
</table>

c. Figure out the following proportions:
   i. \( \frac{5}{15} = \frac{N}{3} \)

Students make Gak (http://www.stevespanglerscience.com/experiment/glue-borax-gak)

e. Students sample three batches of guacamole the teacher had made the prior night at home (using three recipes above). They were then asked to vote as to which two samples tasted the same, and therefore, had the same ratio of ingredients.

Questions:

f. What is the main focus of this lesson? (math, science, or both)

g. What is the relationship between mathematics and science in this lesson?

3) Lesson example #2:

h. Students copy onto their own paper a diagram representing the process of photosynthesis, and use it to answer the question, “Photosynthesis – what is it?”

Students list terms like “oxygen” and “light.” The teacher points out that leaves are little food factories – absorbing sun light and carbon dioxide to produce glucose (its food) and oxygen. Teacher explains that leaves on trees in rain forest are enormous because there is a lot of photosynthesis occurring in them. This part of the lesson emphasizes the effect of different environments on the rate of photosynthesis in plants.

i. Students use fractions to determine the surface area of leaves collected by the teacher in his front yard. Students begin by tracing their leaves onto graph paper. The teacher uses color pencils to draw four different colored boxes on the lower left corner of his paper, labeling the boxes as follows: 1, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$. Then, the teacher puts a dot corresponding to his first color in every box of his graph paper that was completely filled by his leaf. Then, he uses the second color for boxes corresponding to $\frac{3}{4}$, and so on.

<table>
<thead>
<tr>
<th>Color/Fraction</th>
<th>1 (green)</th>
<th>$\frac{3}{4}$ (red)</th>
<th>$\frac{1}{2}$ (yellow)</th>
<th>$\frac{1}{4}$ (blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td># of grid boxes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total S. area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Students find surface areas of their leaves, converting improper fractions to mixed numbers.

j. Teacher explains to the class that leaves in the tropical rain forest are much larger than the leaves used in this lesson (his leaf measured 42 1/4 grid boxes). The large number of leaves in the rain forest = a lot of food shipped from leaves to stems of plants. The class concludes with a
discussion of the relationship between the surface area of a leaf and the rate of photo-synthesis in the plant from which the leaf originated.

Questions:
1. What is the main focus of this lesson? (math, science, or both)
2. What is the relationship between mathematics and science in this lesson?

4) Lesson example #3:

n. The teacher weighs 10 pennies using a single beam balance and gets the weight of 30 g. Next, students calculate the weight of 1 penny (3 g). The class is introduced to the equation $d = \frac{m}{v}$, and students guess the meaning of the letters in the equation. The class discusses the method of displacing water by weight to calculate the volume of an object.

o. Students pour 50 mL of water into a graduated cylinder and gently add in 10 pennies, noting the amount of water before and after the pennies were added. The class finds the average volume of 10 pennies (4 mL). Next, the result is divided by 10 to calculate the volume of one penny (0.4 mL).

p. Students apply the formula $d = \frac{m}{v} = \frac{3\text{ g}}{0.4\text{ mL}} = 7.5\text{ g/mL}$ to find the density of one penny.

q. Students copy the following text from the overhead: “A 1 mL volume of water has a mass of 1 gram. Since density = (m) mass/(v)volume, the density of water is 1 g/mL. Water’s density is used by scientists as the standard of comparison against all other densities measured. If an object is denser than water, it sinks; if it is less dense, it will float. In either case, it will displace an amount of water, since no two objects can occupy the same space at the same time.”

Questions:
1. What is the main focus of this lesson? (math, science, or both)
2. What is the relationship between mathematics and science in this lesson?

III. Workshop #3: November 29, 2012  Theme: Integration

Main Activity: For each of the following short teaching scenarios, answer the following questions:

a. Is this an example of mathematics and science integration? Circle “yes” or “no.”

b. Please rate the extent of integration on a scale 1-5 with 5 as being completely integrated and 1 as being non-integrated. If a scenario is not completely integrated, please indicate which discipline is dominant.

c. Explain what could be done in scenarios rated 1-4 to make them examples of complete integration.

---

1) YES NO  Students in 7th-grade math class are working on graphing data. The teacher has student pairs measure their pulse each minute for 10 minutes, while one student jogs in place.
Your rating: _____  Dominant discipline: _________________

2) YES NO  6th-grade students are studying a unit on earthquakes. The teacher asks students to find the difference between two historical earthquakes using a table involving magnitudes according to the Richter scale.
Your rating: _____  Dominant discipline: _________________

3) YES NO  A 4th-grade class is doing a project on dinosaurs. The teacher asks students to make a chart that compares the sizes of the five different dinosaurs showing their metric heights and weights.
Your rating: _____  Dominant discipline: _________________

4) YES NO Students are investigating ocean floor depths using data from sonar equipment. They are given the equation: D=1/2*T*V, where D=depth in m, T=time in s, V=the speed of sound in water (1534 m/s). The teacher asks the students to compute ocean floor depths given the time required for sound to be sent and return to an echo sounder.
Your rating: _____  Dominant discipline: _________________

5) YES NO During a unit on the solar system, the teacher asks the students to create a scale model that shows the relative size and distance between the Earth and two other planets.
Your rating: _____  Dominant discipline: _________________

6) YES NO  8th-grade students are investigating crystal formation as the liquid in different solutions evaporates. The teacher asks the students to observe and describe various characteristics of the crystals formed when the rates of evaporation, solutes used and container shape are manipulated.
Your rating: _____  Dominant discipline: _________________

IV. Workshop #4: January 31, 2013  Theme: Connections

1) Activity 1: Periodic Table
   a. In this whole group activity, teachers and Fellows identified trends in ordinal data collected during the workshop and organized these trends first into small groups and then into a bigger system, similar in structure to the Periodic Table. The data collected involved words that described the participants’ hobbies, career, family, pets, personality traits, and others. Some of the terms that were generated in this process included: music, teacher, sister, dog, and stressed.

2) Activity 2: Dinosaur Proportions
a. In this activity\textsuperscript{3}, teachers and Fellows made a sketch of an adult person using body proportions of dinosaurs.

3) Activity 3: Rubric for Mathematics and Science Connections
   a. In groups of two, workshop participants prepared scoring rubrics for the following goal:
   “Suppose you have been asked to observe a teacher who is going to attempt to connect mathematics and science in the classroom. Make up a rubric that will help you rate the math and science connections in this lesson.”

   The groups consisted of two teachers, teachers and Fellows, and two Fellows.

V. Workshop #5: March 7, 2013 Theme: Connections
1) Activity 1: Mirror Reflections\textsuperscript{4}
   a. In small groups, teachers and Fellows find the ratio of the length of one’s face to the corresponding length of its mirror reflection.
   b. The group shares results and makes a hypothesis about the ratio common to all workshop participants.

2) Activity 2: Weather patterns
   a. Using real data, teachers and Fellows made predictions about (hand sketches) and then used a computer software to create scatter plots for minimum average monthly temperatures recorded over a 2-year period in New Jersey (United States), Australia, Ecuador, and Alaska.
   b. The group shares results and explains similarities and differences in the graphs.

3) Activity 3: In small groups, Fellows and teachers answer the following questions.
   a. What does it mean to do math? What does it mean to do science?
   b. If you walk into a classroom where the teacher is teaching a lesson, how can you tell that the lesson is a math lesson?
   c. If you walk into a classroom where the teacher is teaching a lesson, how can you tell that the lesson is a science lesson?
   d. Must students be learning something new in both math or science in order for the lesson to integrate math and science?

VI. Workshop #6: April 11, 2013 Theme: Confidence in Math Skills
Main Activity\textsuperscript{5}: In four discipline-specific teams (two science teachers, two mathematics teachers, two science Fellows, and two mathematics Fellows),

\textsuperscript{3} Activity adapted from Quebec Fuentes, S., Garruto, P., & Lockard, F. (2007). What if we were built like dinosaurs? Mathematics Teaching in the Middle School, 13(4), 249-256.

workshop participants performed mathematical task in number theory, algebra, and geometry. References to science content were not included.

VII. Workshop #7: April 25, 2013  Theme: Confidence in Science Skills
1) Main Activity: In two discipline-specific teams (science team and mathematics team), the workshop participants were presented with the following question: How long will it take a quarter to fall from the top of the Empire State Building, assuming no air resistance and non-windy conditions? Each group had to design their own strategy to solve this task, as no further directions for this task were given out. Materials, including measurement sticks, stop watches, basic data (height of the Empire State building), quarters, and others were made available upon request. At the conclusion of the activity, workshop participants verbally described their general experiences and confidence level with this activity.

VIII. Workshop #8: May 30, 2013  Theme: Is it math or is it science?
Closing
1) Activity 1: Filling bottles with water
   a. Repeat parts A-D below for each of the following three vases: cylinder, cone, and curved.
      A. Sketch a graph that represents how you think the water height in the container will change with each ¼ cup of water poured in;
      B. Collect and record the data in a table;
      C. Graph the data on a piece of grid paper;
      D. Compare your initial sketch of the graph with the actual graph.
   b. Repeat parts A-D above for a vase of your own. Draw a picture of the vase.
   c. Sketch a vase that would fill at the rate described by the following graph. Assume that the vase is being filled continuously.

2) Activity 2: Conditions for math and science integration
   Make a wish list of ideal conditions that would allow you to integrate math and science in the future.
### Appendix D

Semi Structured Interview Protocol

<table>
<thead>
<tr>
<th>Teacher Criteria</th>
<th>Teacher Interview Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date: _____________________</td>
</tr>
<tr>
<td></td>
<td>Institutions: ____________________________</td>
</tr>
<tr>
<td></td>
<td>Interviewee (Title and Name): ________________________________________</td>
</tr>
<tr>
<td></td>
<td>Interviewer: ____________________________</td>
</tr>
</tbody>
</table>

**Introductory Protocol**

*To facilitate our note-taking, we would like to video/audio tape our conversations today. Please sign the release form. For your information, only researchers on the project will be privy to the tapes which will be eventually destroyed after they are transcribed. In addition, you must sign a form devised to meet our human subject requirements. Essentially, this document states that: (1) all information will be held confidential, (2) your participation is voluntary and you may stop at any time if you feel uncomfortable, and (3) we do not intend to inflict any harm. Thank you for your agreeing to participate.*

We have planned this interview to last no longer than one hour. During this time, we have several questions that we would like to cover. If time begins to run short, it may be necessary to interrupt you in order to push ahead and complete this line of questioning. You may be contacted for follow up questions to clarify responses you have provided.

**Introduction**

You have been selected to speak with us today because you have been identified as someone who has a great deal to share about teaching, learning, and assessment of collaborative and interdisciplinary science and math instruction. Our research project as a whole focuses on the improvement of teaching and learning activities in science and math, with particular interest in understanding how faculty in academic programs are engaged in these activities to share what we know about making a difference in middle school science and math. Our study does not aim to evaluate you. Rather, we are trying to learn more about teaching and learning, and hopefully learn about faculty practices that help improve middle school student achievement in science and math.

**A. Interviewee Background**

1. Tell me about your teaching experience. How long have you
| Interests, concerns, questions in math and science | been at the current school? in your present position?  
| Math/Science education in other countries | 2. Previous employment?  
| Awareness of middle school students’ strengths and weaknesses (ongoing) | 3. Why did you decide to participate in this study?  
| Mathematics & Science education in other countries | B. Science/Math Education  
| Awareness of fellows’ strengths and weaknesses relative to math and science knowledge (ongoing) | 1. Tell me a little about yourself, where were you raised? Go to school?  
| Collaboration: | 2. What is your highest degree? What is your field of study?  
| o Communication with fellows (Discursive practices, Participation Answer questions Listening skills Writing skills) | 3. Why did you decide to become a teacher? What influenced your decision most?  
| o Positionality | 4. What attitudes do you have towards teaching science and math? Learning science and math? What influenced these attitudes?  
| o Connections formed between fellows’ research and middle school | 5. What content in science and mathematics do you feel proficient? Less than proficient?  
| | 6. What are the challenges and issues being raised in your work as a math/science teacher in your school? Community?  
| | 7. What issues in education do you feel are important? What issues in science and/or math instruction do you feel are important?  
| | 8. What knowledge do you have of math and science instruction in other countries?  
| | 9. What role do you have in changing or contributing to science and math education reform?  
| | 10. What prior knowledge of your fellow’s science/math research do you have? How would you rate your level of interest in your fellow’s research 1 – not interested to 5 – highly interested? What would you like to know/understand about his/her research? In other areas of science/math?  
| Probes for Interview II (post study): | In what ways has your understanding of science and math changed? Why?  
| | What do you know and understand about your fellow’s research?  
| | What questions about science and math have been raised as a result of your collaboration?  
| C. Collaborations | 1. How do you define collaboration? What qualities of collaborations are necessary in order to be effective?  
| | 2. Tell me about your experiences collaborating with others that worked well and did not work well. Do you like working with others? What do you like and dislike about collaborations?  
<p>| | 3. What expectations do you have for your collaboration team in this study? What concerns do you have about teaming with a science/math fellow? How do you see the fellow being involved in your classroom? |</p>
<table>
<thead>
<tr>
<th>Curriculum</th>
<th>4. What strengths do you bring to your collaboration team? What traits would you like to see in your fellow as a collaborator in the study team?</th>
</tr>
</thead>
</table>
| Communication with fellows (ongoing) | 5. Describe the strengths of your collaborators? What areas would you like to see improve in your collaborators?  
6. How would you describe your communication skills? |
| Collaboration with fellows (ongoing) | On a scale of 1 (not confident) to 5 (confident)  
a. Approaching people to engage in conversation.  
b. Being approached by others’ to engage in conversation for the first time.  
c. Asking questions to learn more about others. |
| Communication with project staff (ongoing) | 7. How would you describe your listening skills? Writing skills?  
8. What understandings do you have about your fellow’s research? |
| Values and beliefs about science and math education (initial) | Probes for Interview (post study):  
Is the collaboration working – why or why not?  
How would you describe the level of communication with your partner fellow and teacher?  
How would you like to improve your communication skills?  
How would you like to improve the communication skills of your fellow?  
What concerns do you have about collaborating with a fellow?  
Do you feel well prepared to teach science and math in collaboration with a fellow? |
| Conceptions of collaboration (ongoing) | D. Instruction  
1. How do you plan for instruction? On your own? In collaboration with your team? Please describe the process.  
2. What are your strengths as a teacher? What areas do you want to develop/improve?  
3. What challenges are you confronting in teaching? In students’ learning? |
| Understanding of fellows’ research (ongoing) | 4. How do you see science and math taught from an interdisciplinary perspective? Identify and describe the ways in which interdisciplinary connections links between science and/or math are made (should be made) in class? How do you see science and math taught from an integrated perspective? Identity and describe the ways in which integration of science and mathematics is made (should be made) in class?  
5. How do you see research in science and math influencing your work?  
6. Do you engage in any form of research? Please describe.  
7. How do you define inquiry? How do you engage students in inquiry?  
8. In what ways do you see technology being integrated into a science/math class? |
<table>
<thead>
<tr>
<th>Diversity, adaptation, and modification:</th>
</tr>
</thead>
<tbody>
<tr>
<td>o LEP, SLD</td>
</tr>
<tr>
<td>o Globalization in science and math for international students</td>
</tr>
</tbody>
</table>

9. Describe the experiences you have with individuals with learning disabilities (LD). Please explain the type of disabilities and your level of engagement.

10. What issues/concerns do you have about teaching and learning of science/math for students with LD?

11. How do you see issues related to diversity that include, but not limited to race, gender, ethnicity, language, ability, influencing how science/math is taught (should be taught)?

E. Probes for Post-Observation Debriefing Interviews:
You were asked to present a lesson which showed connections of mathematics and science.

1. What was it about this particular lesson that made you select it for this observation of math and science connections?

2. How do you think your lesson went?

3. What were your learning goals for the students in this lesson? For math? For science? Were these goals achieved? Did you have any other goals for this lesson? If yes, what were they? Math? Science?

4. Did your lesson connect math and science? How do you know this?
   If yes, then ask: How well do you think math and science were connected in your lesson? How do you know this?

5. What was the role of mathematics in this lesson? What role did science play?

6. Would you change anything about this lesson if you could teach it again?
Appendix E

Pre- and Post-Program Attitudinal Teacher/Fellows Survey

GK-12 Pre-program assessment
2012/2013

June 2013

Name:__________________________________________

Date:____________________________________
Professional Practices Survey—pretest
This survey concerns components of the teaching practice of mathematics and science.

Please circle the response that best describes your situation.

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>I often meet with colleagues to work on creating and revising mathematics/science curricula</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
</tr>
<tr>
<td>2</td>
<td>I teach lessons that integrate mathematics and science</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
</tr>
<tr>
<td>3</td>
<td>I have been adequately prepared to encourage female students to participate in math and science activities</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<td>4</td>
<td>I am adequately prepared to encourage minority students to participate in math and science activities</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
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<td>5</td>
<td>I often help students see science in mathematics</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>6</td>
<td>I feel project tasks are best accomplished by teamwork</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<td>7</td>
<td>I am comfortable planning and implementing science field trips</td>
<td>Strongly Disagree</td>
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<td>8</td>
<td>I am comfortable planning and implementing mathematics field trips</td>
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<tr>
<td>9</td>
<td>I often help students see mathematics in science</td>
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<td>Agree</td>
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<tr>
<td>10</td>
<td>I have been adequately prepared to teach students with learning disabilities</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>11</td>
<td>I often meet with colleagues to work on creating and revising interdisciplinary units</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>12</td>
<td>I have been adequately prepared to challenge high-ability students</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>13</td>
<td>I am more comfortable working individually on a project as opposed to in a team</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>14</td>
<td>Science and mathematics are naturally linked</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>15</td>
<td>I am familiar with the content of the national and state mathematics education standards</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<tr>
<td>16</td>
<td>I am familiar with the content of the national and state science education standards</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
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<td>17</td>
<td>I often meet with colleagues to work on creating and revising curricular items that integrate mathematics and science</td>
<td>Strongly Disagree</td>
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<tr>
<td>18</td>
<td>I use a variety of methods to assess student knowledge</td>
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<tr>
<td>19</td>
<td>I often meet with my colleagues to discuss alternative teaching strategies</td>
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<tr>
<td>20</td>
<td>I am comfortable teaching using real-world data</td>
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<tr>
<td>21</td>
<td>I teach interdisciplinary lessons involving science and mathematics</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Agree</td>
</tr>
</tbody>
</table>
1. List the important steps in the scientific process, in order.

2. Please list some benefits you foresee from working with the teachers in your team.

3. Please list some benefits you foresee from working with the graduate students in your team.
4. Please list some benefits you foresee from working with the GK-12 project personnel.

5. Sketch a diagram which depicts integration of mathematics and science education.
6. Describe a lesson you delivered that integrated mathematics and science. In your description, make sure to specify the mathematics and science topics.
7. Ratios and proportional reasoning are two important components of the middle school curriculum. Give three examples of where these skills can be used in real life.

8. What does the integration of mathematics and science education mean to you?

(Number 9 is on the next page…)
9. Please match the following scientist/mathematician with the research result or idea associated with them by writing the corresponding letter in the blank. Do this without looking up the information.

<table>
<thead>
<tr>
<th>Scientist/Mathematician</th>
<th>Research Result/idea</th>
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</thead>
<tbody>
<tr>
<td>Barbara McClintock</td>
<td>Black Holes</td>
</tr>
<tr>
<td>Benoît Mandelbrot</td>
<td>A</td>
</tr>
<tr>
<td>Carl Sagan</td>
<td>calculus</td>
</tr>
<tr>
<td>Charles Boyle</td>
<td>chemistry gas law</td>
</tr>
<tr>
<td>Charles Darwin</td>
<td>dark matter</td>
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<tr>
<td>Charles Lyell</td>
<td>double helix</td>
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<tr>
<td>Craig Venter</td>
<td>fractals</td>
</tr>
<tr>
<td>Edwin Hubble</td>
<td>galaxies</td>
</tr>
<tr>
<td>Enrico Fermi</td>
<td>global warming</td>
</tr>
<tr>
<td>Gottfried Wilhelm Leibnitz</td>
<td>gravity</td>
</tr>
<tr>
<td>Gregor Mendel</td>
<td>heredity</td>
</tr>
<tr>
<td>Harry Hess</td>
<td>Human genome project</td>
</tr>
<tr>
<td>Isaac Newton</td>
<td>If an integer ( n ) is greater than 2, then the equation ( a^n + b^n = c^n ) has no solutions in non-zero integers ( a, b, ) and ( c ).</td>
</tr>
<tr>
<td>Jane Goodall</td>
<td>jumping genes</td>
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<tr>
<td>Jonas Salk</td>
<td>Marine mammals</td>
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<tr>
<td>Leonard Euler</td>
<td>Mars</td>
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<tr>
<td>Mitchell Feigenbaum</td>
<td>natural selection</td>
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<tr>
<td>Pierre de Fermat</td>
<td>nuclear fission</td>
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<tr>
<td>Rachel Carson</td>
<td>particle interactions</td>
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<td>Richard Feynman</td>
<td>Polio vaccine</td>
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<td>Stephen Hawking</td>
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<td>Vera Rubin</td>
<td>polyhedra, graph theory bridges of Konigsburg</td>
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<td>Watson and Crick</td>
<td>primates</td>
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<td></td>
<td>Sea floor spreading</td>
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<td></td>
<td>sequoias</td>
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<td>strata</td>
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</table>
This survey concerns your “Comfort Level” Teaching the following topics. In other words, imagine that you have been called to substitute teach a mathematics or science course the next day. Please circle your response according to your comfort level with each of the following topics. [1] indicates that you are very uncomfortable teaching the topic; [4] indicates that you are very comfortable teaching the topic.

<table>
<thead>
<tr>
<th>MATHEMATICS TOPICS</th>
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<th>Somewhat Uncomfortable</th>
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<td>4 Number Patterns</td>
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<td>5 Exponents</td>
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<td>6 Add, Subtract Integers</td>
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<tr>
<td>7 Multiply, Divide Integers</td>
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<td>8 Add, Subtract Fractions</td>
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<td>9 Multiply, Divide</td>
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<td>45 Voting and Fair Division</td>
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<td>47 Box and Whisker Plots</td>
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<td>52 Forces (gravity, friction)</td>
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How comfortable are you teaching the following interdisciplinary topics?

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Pedagogy: For the following ideas, please circle your comfort level using each science or mathematics teaching methodology, tool, or materials to enhance teaching and learning.

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Perceptions Toward the Integration of Mathematics and Science

For each statement, choose one response shown below (SD, D, N, A, SA) and write it in the blank. Please write comments.

Answer: SD=Strongly disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly agree

______ For many topics, integrating mathematics and science is a preferable method than teaching the content in separate lessons.

Comments:

_____ I feel I have sufficient background in mathematics and science to integrate both in lessons.

Comments:

_____ I am aware of curriculum materials designed to integrate mathematics and science.

Comments:

_____ There’s not enough time during most lessons to integrate mathematics and science content.

Comments:

(Questionnaire items continued on the next page)
Please write comments.

_____ Students get confused when mathematics and science are integrated in lessons.

Comments:

_____ Classes for gifted students would be most appropriate place for integrating mathematics and science.

Comments:

_____ Hands-on activities are more appropriate in science lessons than in mathematics lessons.

Comments:

_____ During talks with my colleagues and by observing lessons, it appears to me that integrating mathematics and science is common.

Comments:

These questionnaire items were adapted from *Preservice and Practicing Elementary Teachers’ Perceptions Toward the Integration of Mathematics and Science* in Lehman (1994).
**Attitudes and Perceptions Related to Integration of School Science and Mathematics**

Directions: For each pair of words below place an X in the blank that best tells how you feel about INTEGRATION OF MATHEMATICS and SCIENCE EDUCATION

| beneficial | ______:_______:_______:_______:_______ | harmful | ______:_______:_______:_______:_______ |
| passive | ______:_______:_______:_______:_______ | active | ______:_______:_______:_______:_______ |
| understandable | ______:_______:_______:_______:_______ | mysterious | ______:_______:_______:_______:_______ |
| frill | ______:_______:_______:_______:_______ | necessary | ______:_______:_______:_______:_______ |
| deep | ______:_______:_______:_______:_______ | shallow | ______:_______:_______:_______:_______ |
| bad | ______:_______:_______:_______:_______ | good | ______:_______:_______:_______:_______ |
| changing | ______:_______:_______:_______:_______ | constant | ______:_______:_______:_______:_______ |
| tool | ______:_______:_______:_______:_______ | toy | ______:_______:_______:_______:_______ |
| strange | ______:_______:_______:_______:_______ | familiar | ______:_______:_______:_______:_______ |
| weak | ______:_______:_______:_______:_______ | strong | ______:_______:_______:_______:_______ |
| simple | ______:_______:_______:_______:_______ | complicated | ______:_______:_______:_______:_______ |
| confining | ______:_______:_______:_______:_______ | expanding | ______:_______:_______:_______:_______ |
| sad | ______:_______:_______:_______:_______ | happy | ______:_______:_______:_______:_______ |
| brave | ______:_______:_______:_______:_______ | scared | ______:_______:_______:_______:_______ |
| slow | ______:_______:_______:_______:_______ | fast | ______:_______:_______:_______:_______ |
| crutch | ______:_______:_______:_______:_______ | tool | ______:_______:_______:_______:_______ |
| boring | ______:_______:_______:_______:_______ | exciting | ______:_______:_______:_______:_______ |
| jump in | ______:_______:_______:_______:_______ | hold back | ______:_______:_______:_______:_______ |
| hard | ______:_______:_______:_______:_______ | easy | ______:_______:_______:_______:_______ |
| more | ______:_______:_______:_______:_______ | less | ______:_______:_______:_______:_______ |

Appendix F

Teacher Consent Form

CONSENT FORM FOR ADULTS: Teachers

Please read below with care. You can ask questions at any time, now or later. You can talk to other people before you fill in this form.

Study’s Title: GK-12 Fellows in the Middle: Partnerships for Inquiry and Interdisciplinary Middle School Science and Mathematics (at Montclair State University)

Why is this study being done? We are trying to understand the impact of a program that involves Science, Technology, Engineering, and Mathematics (STEM) graduate students working with middle school teachers to bring their knowledge and research into middle schools, and to integrate their knowledge of their subject with middle school teachers’ expertise in teaching. Information about our project can be obtained by going to our web site www.csam.montclair.edu/gk12/, or by contacting us directly. (See the contact information, below.)

What will happen while you are in the study? You will team up with another teacher from your school and a pair of STEM graduate students (“Fellows”) to create lessons, field trip activities and projects in science and math. During the summer, you will learn about particular teaching approaches we want you to try, and you will develop lesson plans with your graduate student-partner. During the school year, the graduate student will act as a “resident scholar” for your students, first observing, then contributing, then (on occasion) delivering lessons. (These lessons will sometimes be videotaped, to help the Fellow improve, and to help us understand his development in the program. Those videotapes will be analyzed and stored securely during and after the program.) You will bring your expertise in teaching methods to help the Fellow use his/her expertise in their field of STEM research into the classroom and connect it with the students’ curriculum, and the two field trips being scheduled for the year.

At the beginning and end of the school year, you will take an attitudinal survey, so we can determine changes in your attitudes toward, and knowledge of, teaching and STEM content. In addition, we will periodically ask you to submit curricular materials that you design and/or deliver (ex: lesson plans), as well as other materials (ex: written responses to Fellows’ work, self-reflections), related to the program’s activities and objectives.
(Selected lessons will sometimes be observed and/or videotaped to help us understand the impact of the program on your perceptions, attitudes, and practices related to the program’s objectives.) Those videotapes will also be analyzed and stored securely during and after the program.

You will keep a portfolio of your students’ work during the year to help us understand how the program has affected your teaching and your students. We will also be interviewing you about four times during the course of the year to help us understand your growth in the program.

More detailed information about your role in the program can be found in the NSF proposal, and the Teacher Agreement, which you should read before signing this document.

**Time:** This study will take about 5 hours per week, over and above your usual teaching duties, for the whole year. (This is an average, and may vary.) During the summer, there are professional development workshops and collaborations with your Fellow-partner. During the school year, there are monthly meetings, fieldtrips, interviews, and prep work that will take time over and above your usual work duties.

**Risks:** During the program, you will have an opportunity to comment on and possibly criticize your partner-Fellow, your teaching colleagues or Research Team members. You will also have the opportunity to possibly reveal damaging attitudes towards teaching, pedagogical approaches the researchers favor, or your middle school students. If these comments became public knowledge, your reputation might suffer. To mitigate this risk, only Dr. Mika Munakata and Eliza Leszczynski will have direct access to your comments in interviews or on the attitudinal surveys, and they will code them to remove identifiers, so other research team members cannot identify you.

You may also feel coerced to participate: the compensation (up to $3,000 for the year) is substantial. We remind you that this compensation is tied to fulfillment of your duties as a teacher in the program, but not tied to achievement of program goals. To help you understand the financial consequences of withdrawing from the program, we have attached a schedule showing the payments you would receive during your participation, below. If you withdrew, you would forfeit any payments after your withdrawal, though some payments may be pro-rated according to your participation.

**Payment schedule:**
Payment #1: October 30, 2012 upon successful completion of Summer Institute, and completion of pre-program assessments, in the amount of $1000.
Payment #2: February 28, 2013 upon successful completion of professional development workshops, program assessments, and classroom mentoring of Fellows, in the amount of $1000.
Payment #3: June 30, 2013 upon successful completion of professional development workshops, classroom mentoring of Fellows and post-program assessments, in an amount
ranging between $0 and $1000 depending upon your participation as detailed in the Teachers Agreement, which you should read before signing this document.

Benefits: You may benefit from this study by developing your pedagogical skills and by increasing your STEM content knowledge in ways relevant to your teaching. You may also obtain professional development credit for your participation. You may also benefit by taking advantage of opportunities to become more professionally active by presenting at conferences. You will also benefit from the financial compensation provided to you for participating in the program.

Others may benefit from this study in several ways. First, we may learn more about how to produce good STEM researchers who can communicate their discoveries to the general public. Second, we may learn more about how to teach STEM content to middle school students, and increase their enthusiasm for pursuing STEM-related careers. Third, we may learn more about how to increase the quality of STEM education in middle school, and the knowledge and skills of science and math school teachers.

Who will know that you are in this study? This study has been publicized, and people will know you are a part of it. But, the content of your participation in the program will be confidential. We will publicize results, but your identity will not be linked to any presentations or publications that the program produces. For example, if we use a quote from a program participant in a presentation, we will use a pseudonym instead of that participant’s real name.

Do you have to be in the study? You do not have to be in this study. You are a volunteer! It is okay if you want to stop at any time and not be in the study, though withdrawal from the study will have consequences (such as forfeiting your compensation, and disrupting your partners’ participation in the program), so it is important that you carefully consider your decision to participate. You do not have to answer any questions you do not want to answer. Your superiors will not know about it.

Do you have any questions about this study? Phone or email Dr. Mika Munakata at munakatam@mail.montclair.edu or Eliza Leszczynski at leszczynskie@mail.montclair.edu, Department of Mathematical Sciences, Montclair State University, 1 Normal Avenue, Montclair, NJ 07043 973-655-5132.

Do you have questions about how this study relates to your school’s science and math curriculum? Contact XXX at XXX.

Do you have any questions about your rights? Phone or email the IRB Chair, Dr. Debra Zellner (reviewboard@mail.montclair.edu, 973-655-4327)
The above consent document and signature form below is for you to keep; please return the second signature form to the research team.

Participant Copy

GK-12 Fellows in the Middle: Partnerships for Inquiry and Interdisciplinary Middle School Science and Mathematics (at Montclair State University)

It is okay to use my data in other studies:

Please initial: _____ Yes _____ No

I would like to get a summary of this study at the end of the program: (We will send you a link to the summary at the conclusion of the study.)

Please initial: _____ Yes _____ No

It is okay to videotape/audiotape me while I am in this study.

Please initial: _____ Yes, it’s OK _____ No, I don’t want to be videotaped/audiotaped

It is okay to use my audiotaped/videotaped data in the research.

Please initial: _____ Yes, it’s OK _____ No, I don’t want my videotaped/audiotaped data to be used in the research

If you choose to be in this study, please fill in your lines below.

______________________________  ______________________________  ____________________
Print your name here             Sign your name here            Date

______________________________  ______________________________  ____________________
Mika Munakata                  Name of Principal Investigator  Signature


Please return this document, signed and initialed where indicated, to the research team:

Participant Copy

GK-12 Fellows in the Middle: Partnerships for Inquiry and Interdisciplinary Middle School Science and Mathematics (at Montclair State University)

It is okay to use my data in other studies:

Please initial: _____Yes  _____No

I would like to get a summary of this study at the end of the program: (We will send you a link to the summary at the conclusion of the study.)

Please initial: _____Yes  _____No

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Please initial: _____Yes, it’s OK  _____No, I don’t want my videotaped/audiotaped data to be used in the research

If you choose to be in this study, please fill in your lines below.

________________________  ___________________  ___________________
Print your name here        Sign your name here        Date

Mika Munakata
Name of Principal Investigator

____________________        ___________________        ___________________
Signature                    Date
Appendix G

Parent/Guardian Consent Form

Please carefully read the information below. You may ask questions at any time, now or later. You may talk to other people before you complete this form. Please look over the contact list, below, to find people who can answer your questions.

Program’s Title: GK-12 Fellows in the Middle: Partnerships for Inquiry and Interdisciplinary Middle School Science and Mathematics (at Montclair State University)

Who am I? I am Dr. Mika Munakata from the Department of Mathematical Sciences at Montclair State University. I am the director of the program. Information about our project can be obtained by going to our web site www.csam.montclair.edu/gk12/, or by contacting me directly. (See the contact information, below.)

What, and why, am I researching? I am trying to understand the impact of a program that involves Science, Technology, Engineering, and Mathematics (STEM) graduate students working with middle school teachers to bring their knowledge and research into middle schools, and to integrate their knowledge of their subject with middle school teachers’ expertise in teaching. With the approval of your district and school, we have matched your child’s science and/or math teachers with Montclair State University STEM graduate students. As a team, your child’s science and math teachers, our graduate students and their research advisors will create lessons, field trip activities and projects in science and math. If our STEM graduate students can help middle school teachers inspire their students, and help them improve the achievement of their students in science and math, then our program may become a model for training STEM graduate students and for exposing middle school students to current math and science research ideas.

What will participating in the research involve? Your child’s math and/or science classes will be augmented by having a “resident scientist” or “resident mathematician” (our STEM graduate students) in their class twice a week, to help bring new content to their teacher’s regular instructional curriculum. They will work with teachers to develop and present lessons and projects that integrate the math and science topics your child is studying. The graduate students are role models of young scientists, especially as they make connections to the math and science topics studied in middle school to the math and science investigated in college and industry. A major component of our project includes interdisciplinary lessons designed around the following field trips:
The New Jersey School of Conservation in October
Montclair State University for a Middle School Math & Science Day in June.

To help me measure how successful our resident scholars are in inspiring your child and helping him/her learn more about science and math, we need to administer some surveys both before and after the school year. The surveys are designed to help me see how your child and his/her classmates’ attitudes about STEM have changed over the year, and whether our resident scholars have helped them achieve a better understanding of science and math because of this extra contact with young scientists. The surveys will not be used in assigning a grade to your child, and their results will not be available to the school district or be included in any way in your child’s educational records. All survey data will be immediately coded by our research team to preserve your child’s confidentiality. You may view sample survey and science questions by going to our website (http://www.csam.montclair.edu/gk12/) and clicking on the ‘Assessment’ link.

The school district has also agreed to allow us access to coded NJ ASK math and science scores. At the end of the school year, two members of our research team will look at some representative samples of student work collected by their teachers. (With your permission, some of your child’s work may be included.) We use aggregate class results of the attitudinal surveys, NJ ASK results and sample student work (portfolios) to help us determine which educational activities are most beneficial for the students. The surveys will be completed during regular class periods.

In addition, if you and your child agree, he or she may be invited to participate in three videotaped Focus Group Interviews to discuss the program’s activities. These Groups will meet near the start, middle and end of the school year, and last for about an hour each. Focus Groups consist of 5 – 7 students from your child’s class. The videotapes will be used only by the interviewer to create an accurate written record of the interview. The teacher, resident scholars and school board officials will not have access to these videotapes or any other records of the Focus Groups.

We will also be videotaping a few classes, when the resident scholars are actively helping to teach the class. This is to help the resident scholar reflect on and improve their communication of science or math. Your child may appear in some of those videos. If you or your child does not want to be videotaped, we will be careful to make arrangements that they aren’t filmed. (You may specifically choose not to have your child videotaped – please see more on this below.) Neither the focus groups nor the in-class videotaping are used for evaluating your child, and neither will be available to school district officials.

Overall, your child’s participation in this study will be completed entirely in class, except for field trips and (if you choose) the 3 Focus Group Interviews. (Field trips associated with this study will be run as usual by the school; you will receive the usual requests for permission for your child to go on every field trip.) All other activities are in-class activities that don’t interfere with the standard curriculum appropriate to your child’s grade level.
Are there any risks we foresee in this study? Your child may become anxious because of the surveys we’re asking them to complete at the start and end of the year, but we will reassure them that these are not for grades or part of their educational record, and will be confidentially held by the research team. Also, your child may be uncomfortable being videotaped in class. They or you may always opt out of this portion of the study – we will seat your child out of sight of the video camera – but the contents of the tape will only be used for helping the resident scholars’ development as communicators of science and math, not to evaluate your child.

Are there any direct benefits for my child? Yes; though this study is primarily aimed at developing our STEM graduate students into successful communicators of their research, an important secondary benefit is the inspiration and achievement we cultivate in the middle school science and math classrooms. (After all, that is how we are measuring the success of our program.) We think that students with resident scholars in the classroom will benefit in many ways: they will become more aware of careers that involve science and math, they will learn and remember more math and science, and their achievement on state tests will improve.

What if I don’t want my child to be in the study? As we have discussed above, there are several parts of the study that you may freely opt your child out of, if you choose, but it may not be possible in all cases to remove your child entirely from this program without a significant amount of upset to your child’s schooling situation. For some parts of the study, such as the surveys and tests, you can always ask us to remove your child’s data from the study, even if they have already completed the survey. If you are concerned about the program, please consult the contact list below to find out how we can help address your concerns and accommodate your child.

Who will know that my child might be in this study? We will keep all the data we collect in the classroom confidential, and restrict access to the research team only. The classroom teacher, resident scholars and school officials will not have access to any individually-identifiable results of tests or surveys, though they may be told about aggregate statistics of those assessments to help improve instruction at your school. Though it will be general knowledge that your child will be in a “GK-12 Fellows in the Middle” classroom, no-one – not the teachers, principal or other school board officials – will know the extent of your child’s participation in the research. This consent document, and the parts of the study you indicate consent for, will remain confidential. Your child will not be linked by name to any presentations or publications that result from this research. We will keep who he or she is confidential according to the law. If any direct quotes from the interviews, surveys or assessments are used in publications or professional presentations, your child’s identity will be masked through the use of a pseudonym or numerical code. During the course of the study all data will be secured in the researchers’ locked offices and access to the data will only be granted to those who have permission.
Who can I talk to about this program? If you have questions about the GK-12 Fellows program, please email, mail or phone Dr. Mika Munakata at munakatam@mail.montclair.edu or at the Department of Mathematical Sciences, Montclair State University, 1 Normal Avenue, Montclair, NJ 07043 or 973-655-5132.

If you have questions about how this study relates to your school’s science and math curriculum, email, write or phone Ms. XXX at XXX.

If you have questions about your rights as the parent/guardian of a child asked to participate in research, email or phone the IRB Chair, email or phone the IRB Chair, Deborah Zellner (reviewboard@mail.montclair.edu, 973-655-4327).
Consent Documentation

*One copy of this consent form is for you to keep; please return the other copy with the completed signature page to the research team.*

Your child’s name (please print): _____________________________________

If you choose to have your child participate in this study, please fill in the lines below.

Name of Parent or Guardian ________________________ Signature of Parent or Guardian ________________________ Date __________

There are some aspects of the study you may not want your child to participate in. The table below provides you the opportunity to opt in or out of each of these aspects of the study. Please initial the appropriate box related to the study component:

<table>
<thead>
<tr>
<th>Study Component</th>
<th>YES:</th>
<th>NO:</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is okay to videotape my child during classroom sessions with the resident scholar.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is okay to include some of my student’s coursework in a portfolio of student accomplishments assembled by his/her teacher.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is okay for my child to participate in Focus Group Interviews, which will be videotaped.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is okay to use my child’s data in future studies.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

I would like to get a summary of this study at the end of the program: (We will send you a link to the summary at the conclusion of the study.)

Please initial ______ Yes ______ No

Mika Munakata ________________________ ________________________ Date __________
Name of Principal Investigator Signature Date
Appendix H
Student Assent Form

STUDENT ASSENT FORM

Please read the information below. You can ask questions at any time. You can talk to other people before you complete this form.

**Who are we?** We are the directors of the project. Our names are Dr. Mika Munakata and Ms. Eliza Leszcynski. You can learn more about our project at www.csam.montclair.edu/gk12/. You can also contact us directly. (See the contact information below.)

**Why is this study being done?** We are trying to understand how science and math graduate students can help middle school students. We also want to improve how graduate students describe their research.

**What will happen while you are in the study?** Your teacher will be working with a graduate student. The graduate student will be in your classes explaining the science and math that he or she studies in your classroom. They will also plan two field trips for you that will help you learn science and math.

You will be asked to complete a survey at the start and the end of the school year. These will help us determine the impact of the program. Your responses on the surveys won’t be part of your grade for the course. Your teacher won’t know about your responses.

There will be a person observing the graduate students about three times this year. The person may videotape the graduate student and your teacher. You don’t have to be in the videotape. The only reason they are taping is to help the graduate students.

You may also volunteer to be part of a student Focus Group. The Focus Group will meet with a researcher to talk about the program. The Focus Group will happen later in the year, and will be videotaped.

**Time:** This study will take the whole school year. Most of the activities will happen during class time. The field trips and the Focus Group will happen outside of class.

**Risks:** The field trips will happen away from school, so there may be some risks. We will ask your parents’ or guardians’ permission for field trips. Because all of your
classmates and your teacher are part of the study, you may feel pressured to participate in all of the program’s activities. It’s important to remember that all of your classmates are participants in it just like you. The only people that are really interested in having you in this study are the researchers from Montclair State, and they don’t have any power over you.

You can choose not to be a part of a few activities without anyone knowing. For example, you can choose not to answer survey questions. If you feel uncomfortable about the whole idea of having a graduate student help your teacher, you should talk to your parent or guardian or us about it.

Benefits: You may benefit from this study. You may also learn and remember more math and science. You may do better on state tests.

Others may benefit from this study in several ways. First, we may learn more about how to produce good scientists. Second, we may learn more about how to teach science and math to middle school students. Third, we may learn more about how to improve science and math education in middle school.

Who will know that you might be in this study? Your participation in the program will be known, since your entire class will be a part of it. But only the researchers will know if you completed the surveys, and they will keep that a secret.

Do you have to be in the study? You do not have to be in this study. We won’t get mad with you if you say no. But, it might be very difficult to completely leave the program, and you may have to change classes. We will try to help if you have any problems with being in the study, but we can’t promise we can fix them. When researchers ask about your experiences in the classroom, you do not have to answer any questions you do not want to answer.

Who can I talk to about this program? If you have questions, please contact Dr. Munakata or Ms. Leszczynski. munakatam@mail.montclair.edu, leszczynskie@mail.montclair.edu.
Montclair State University
1 Normal Avenue, Montclair, NJ 07043
973-655-5132
You can also contact Ms. XXX.
XXXschools.com
Address: XXX
If you have questions about your rights as a student in the program, please contact Deborah Zellner: reviewboard@mail.montclair.edu, 973-655-4327
Assent Documentation

One copy of this complete assent form is for you to keep. Please return the other copy with the completed signature page to the research team.

GK-12 Fellows in the Middle: Partnerships for Inquiry and Interdisciplinary Middle School Science and Mathematics (at Montclair State University)

If you choose to participate in this study, please fill in the lines below.

Print your name here ___________ Sign your name here ___________ Date ___________

Name of Parent or Guardian ___________ Signature of Parent or Guardian ___________ Date ___________

There are some aspects of the study you may not want to participate in. The table below provides you the opportunity to opt in or out of each of these aspects of the study. Please initial the appropriate box related to the study component:

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I would like to get a summary of this study at the end of the program: (We will send you a link to the summary at the conclusion of the study.)

Please initial ________ Yes ________ No

Mika Munakata ____________
Name of Principal Investigator ____________ Signature ____________ Date ____________