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**The Integration of Mathematics in Middle School Science: Student and Teacher Impacts  
Related to Science Achievement and Attitudes Towards Integration**

A Dissertation Presented

by

**Luisa McHugh**

to

The Graduate School

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Abstract of the Dissertation

**The Integration of Mathematics in Middle School Science: Student and Teacher Impacts**

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Contemporary research has suggested that in order for students to compete globally in the 21st century workplace, pedagogy must shift to include the integration of science and mathematics, where teachers effectively incorporate the two disciplines seamlessly. Mathematics facilitates a deeper understanding of science concepts and has been linked to improved student perception of the integration of science and mathematics. Although there is adequate literature to substantiate students' positive responses to integration in terms of attitudes, there has been little empirical data to support significant academic improvement when both disciplines are taught in an integrated method.

This research study, conducted at several school districts on Long Island and New York City, New York, examined teachers' attitudes toward integration and students' attitudes about, and achievement on assessments in, an integrated 8<sup>th</sup> grade science classroom compared to students in a non-integrated classroom. An examination of these parameters was conducted to analyze the impact of the sizeable investment of time and resources needed to teach an integrated

curriculum effectively. These resources included substantial teacher training, planning time, collaboration with colleagues, and administration of student assessments.

The findings suggest that students had positive outcomes associated with experiencing an integrated science and mathematics curriculum, though these were only weakly correlated with teacher confidence in implementing the integrated model successfully. The positive outcomes included the ability of students to understand scientific concepts within a concrete mathematical framework, improved confidence in applying mathematics to scientific ideas, and increased agreement with the usefulness of mathematics in interpreting science concepts. Implications of these research findings may be of benefit to educators and policymakers looking to adapt integrated curricula in order to improve the preparation of students to learn and achieve in a global society.

## **Dedication Page**

I remain forever grateful to my mother, who read to me as a child and taught me to love the pursuit of knowledge, and to my father who I know would have been proud.

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## **Chapter 1**

### **Introduction**

#### **1.1 Thesis**

For over a century, considerable research has been conducted on the integration of mathematics into the science classroom and its effect on student achievement. Recently, in an effort to improve science, technology, engineering and mathematics (STEM) education, federal and state agencies have offered substantial incentives for STEM teacher training and the implementation of innovative and rigorous STEM coursework into schools (President's Council of Advisors on Science and Technology [PCAST], 2010). If one goal of integration is for students to utilize skills from both disciplines in problem solving activities, then an integrated science curriculum should enable students to perform better on both mathematics and science assessments (National Academy of Sciences, 2014).

The purpose of this study was to examine the implementation of mathematics and science infusion in several middle schools in New York State, as well as to analyze data on a specific infused topic administered at a selected middle school in a large school district on Long Island, New York. In order to understand whether integration affects students' science achievement, it is necessary to analyze assessment scores and students' attitudes toward an integrative curriculum. Since there may be an association between the confidence of a teacher and his or her ability to implement an integrative lesson, it is important to examine teacher attitudes, as well (Stohlmann,

Moore, & Roehrig, 2012). For the purposes of this study, the integrated classes were labeled *infusion* classes and the non-integrative classes were the *comparison* classes.

This chapter provides an overview of the study starting with the background for exploring implementation of mathematics integration into science classes (Section 1.2), and the nature of assessing student achievement and student and teacher attitudes (Section 1.3). The problem statement is identified (Section 1.4) and the rationale for conducting the research is presented (Section 1.5). Research questions are defined and the methodology is briefly introduced (Section 1.6). The chapter concludes with the significance of conducting the research and its contribution to the field of science education (Section 1.7).

## **1.2 Background**

Prior to 2002, the United States Federal Government allowed individual states to determine educational frameworks, standards and assessments. In 2002, the New York State Education Department (NYSED) implemented educational mandates specified by the federal government in the *No Child Left Behind Act* (NCLB, 2001). Standardized testing became the measure of accountability with which the federal government determined the success or failure of schools. One section of the law, Title II Part B, is the *Mathematics and Science Partnership*. The purpose of this section was to encourage states to develop more rigorous mathematics and science curricula in order for students to meet the standards expected for postsecondary study in engineering, mathematics, and science.

The current national science and mathematics standards that guide both state curricular frameworks and local courses of study affirm the importance of integrating science and mathematics education. According to the National Research Council, the science program should be coordinated with the mathematics program to enhance student understanding of mathematics

in science and to improve overall student understanding of scientific principles (National Research Council, 1996, 2012). The *Next Generation Science Standards* (NGSS Lead States, 2013, 2014) and *Atlas of Science Literacy* (American Association for the Advancement of Science [AAAS], 2001) have re-emphasized the crosscutting experiences students should have in relation to specific science concepts. Crosscutting concepts provide students with opportunities to experience connections within disciplines and across different disciplinary content (National Research Council, 2012). James Beane (1991, 1996, 1997) suggests that in order for integrated courses to be more successful at a higher level, students need to experience this type of instruction in earlier grades. Reinforcing this idea, the National Council of Teachers of Mathematics (NCTM), stated that mathematics curricula, particularly in grades 5-8, should include mathematical connections to other disciplines (NCTM, 1989, 2000).

### **1.3 Assessing Science Achievement in Middle School**

NCLB (2001) mandated that by 2007-2008, students in all 50 states must be tested in science at least once in elementary school (3-5), once in middle school (6-9) and once in high school (10-12). Most eighth grade students in New York State take a science assessment known as the *New York State Intermediate Level Science* (ILS) exam. In addition to science content, this exam includes questions that require different levels of mathematical knowledge and skills. The ILS exam highlights concepts and practices based on the NYSED Mathematics, Science and Technology (MST) Core Curriculum (NYSED, 1996). The MST Core Curriculum is a detailed description of the learning standards in mathematics, science, and technology and its Key Ideas and Performance Indicators. According to this document, “Key Ideas are broad, unifying, general statements of what students need to know, and the Performance Indicators for each Key Idea are

statements of what students should be able to do to provide evidence that they understand the Key Idea” (NYSED, 1996, p. 3).

There are seven learning standards for MST. Although mathematics, science and technology education are included in all of the standards, Standard 3 is known as the "Mathematics Standard," Standard 4 is known as the "Science Standard," and Standard 5 is known as the "Technology Education Standard." Standards 1, 2, 6 and 7 emphasize the interconnection of mathematics, science and technology through analysis and application. This document does not advise teachers how to teach the curriculum or what the middle school science course syllabus should be, but it speaks to the material that will be assessed on the ILS Examination.

Although New York State middle schools are bound by the MST Core Curriculum, standardized testing varies by district. In 8<sup>th</sup> grade classes in other school districts on Long Island, some or all students take advanced Regents Level courses in either Earth Science or Living Environment. In these school districts, the norm is for the students not to take the ILS exam and only take the New York State Regents in that course. However, some school districts require the 8<sup>th</sup> grade students to take both the Regents exam and the ILS exam.

#### **1.4 Statement of the Problem**

The purpose of this study is to evaluate the effectiveness of the *Mathematics infused Science Program* (MiSP), an integrated science and mathematics curriculum developed by researchers at Hofstra University (Hofstra University, 2000). The overall analysis compared integrated science content assessment scores between the infusion and the comparison groups. Identical topics were taught in both the infusion and comparison classes, however, in the infusion group, students were taught the science topics with lessons that had added mathematical



components of graphing. These graphing components included constructing and interpreting graphs, determining slope and calculating the equation of the line. The comparison group was taught science topics either without the graphing components at all, or with the construction of a graph without the further examination of slope or determining the equation of the line.

The mathematics in the infusion class was structured with three stages of graphing. Each stage was introduced twice during two different science lessons for a total of six mathematics infused science units throughout the year. The integration strategy was concentrated within these six units rather than evenly distributed throughout the entire curriculum. The stages were differentiated as follows:

- Stage 1: Students utilized experimental data, either supplied or obtained during the particular lesson, to construct a line graph. Skills addressed at this stage included gathering data, where applicable, and representing the data graphically.
- Stage 2: The above stage with the addition of the calculation of slope and visual understanding of linear and non-linear relationships. Students applied the slope calculation to determine the relationship between the independent variable and the dependent variable, as well as comparing the numerical value of the slope for the data lines of multiple results.
- Stage 3: The above two stages with the added skill of determining the equation of the line. Calculating and utilizing the equation of the line enabled students to predict various outcomes within the data set or to extrapolate beyond the data.

In the comparison group, the same topics were taught, but not in the infusion lesson format. The graphing introduced to the comparison group was only at Stage 1. The lessons taught in each MiSP unit lasted approximately five learning periods of 40-42 minutes each. The infusion classes and comparison classes were both taught by teachers who had undergone professional development in the program (described in Section 3.3), an essential component of effective STEM integration initiatives (Frykholm & Glasson, 2005; Hynes & Santos, 2007; United States Department of Education, 2000).

In both groups, pre- and post-assessments were administered at the beginning and end of the academic year. Additionally, in one setting with a smaller population, a pre- and post-lesson assessment was administered for the lesson on thermal conduction to both groups. This allowed for data analysis within both the large-scale group and the smaller subgroup, so the effectiveness of the overall program and an individual school-level unit could be explored. Utilizing surveys, a second goal was to determine whether students and teachers recognized the value of interconnectedness of the disciplines and felt confident in their required performance skills. All instruments are described in detail in Chapter 3.3.

## **1.5 Rationale for the Study**

The opportunity for students to experience authentic mathematical applications in science learning is important. Research has suggested that mathematical connections can help students relate mathematical topics to their everyday experiences, improve their knowledge of mathematics, and help them see mathematics as a useful and engaging discipline (Berlin & White, 1994; Bragow, Gragow, & Smith, 1995; Sherrod, Dwyer, & Narayan, 2009). Czerniak, Weber, Sandmann, and Ahem (1999) suggested that connecting mathematics and science might enable students to become more interested and motivated in their science and mathematics classes. Other research found that integration supports learning because connecting concepts to prior knowledge is how our cognitive abilities work best (Bransford, Brown, & Cocking, 2004; Osborne & Wittrock, 1983). Despite the overwhelming philosophical support for an integrated curriculum, there is a scarcity of empirical research supporting an integrated curriculum over a traditional discipline-specific one (Berlin & Lee, 2005; National Academy of Sciences, 2014). Most previous studies were based on testimonials and were more qualitative in nature. This lack

of data was the impetus for this study of approximately 1700 students from several Long Island and New York City middle schools and their 28 teachers, and an in-depth analysis of 136 students at a middle school in the region. This study was part of the MiSP program, a three-year project funded by the National Science Foundation (NSF) and conducted by Hofstra University's Center for STEM Research.

This study analyzed previously collected data from the MiSP program that had obtained an exempt status from Hofstra University's Institutional Review Board (IRB # 294821-1). This exemption was also recognized by Stony Brook University's Office of Research Compliance (IRB #362864-1). The program supported the incorporation of mathematics into the New York State ILS curriculum for 8<sup>th</sup> grade students as well as 8<sup>th</sup> grade New York State Regents-level courses in Living Environment and Earth Science. Examples of laboratory experiences included topics in density, thermal conduction, and global warming. Each laboratory investigation administered to the infused classes had a graphing component, either at stage 1, 2 or 3, depending on when the lesson was taught during the academic year, whereas the comparison group was taught the same lesson topic but without most of the graphing components.

This study examined student achievement measured by an integrated content assessment and student attitudes toward integration in both infused and comparison 8<sup>th</sup> grade science classrooms. In addition, students at a particular large suburban school district on Long Island, New York provided data for a pre-/post-analysis on a lesson assessment on thermal conduction between treatment and comparison classes. The study utilized assessment tools that were extensively pilot tested prior to administration to study participants.

The results of this study may be useful to individuals involved in efforts to support middle school STEM education in the United States. This includes policy makers, school leaders,

mathematics and science educators, as well as those involved in teacher education and professional development.

## **1.6 Research Questions and Methods**

Data from the assessments utilized in the study provided specific indications of success in applying graphing skills within the science context. These findings can be used to design curricula for integrated programs in middle school. The following research questions guided this study:

- Research Question 1: Have students' understandings of integrated science content improved as a result of the infused curriculum?
- Research Question 2: Have students' attitudes towards the relationship between mathematics and science changed as a result of participating in the infused curriculum?
- Research Question 3: How do students' views on integration correlate with their performance on an integrated science assessment?
- Research Question 4: How does teacher confidence relate to science learning outcomes and student attitudes?

Data were collected from middle school students and teachers of the infusion and comparison classes. To ensure student data remained confidential, a random identification number was assigned to each student. An attitude assessment and an integrated content assessment were administered to all students (infusion and comparison) at the start and end of the academic year. At one location, student pre- and post-lesson assessments were administered to both infusion and comparison classes at the start and end of the lesson on thermal conduction. Surveys on confidence were completed by teachers in the infusion group at the end of the MiSP program. Since some of the teachers ( $N = 28$ ) were previously comparison teachers the year before, they were able to express their opinions as both infusion and non-infusion instructors.

The integrated content assessment and the thermal conduction lesson assessment tools were developed by the MiSP project after consulting with educators and a review of the state science assessments and science textbooks. Content and lesson exam items were piloted and selected based on an analysis of student responses. The content exam asked general mathematical questions on graphing components similar to what might be seen on the ILS exam, whereas in the lesson assessment, the mathematical questions were embedded within the assessment as it pertained specifically to the particular science content presented. The lesson assessment consisted of short answer and open-ended questions that were systematically scored to compare matched sample pre- and post-assessments as well as independent samples between the infused and comparison groups. Instrument quality as related to reliability and validity are discussed in detail in Chapter 3.

## **1.7 Overview of the Thesis**

Since traditional educational practices have placed emphasis on separate and distinct disciplines, particularly in science and mathematics, this raises the question as to whether students can integrate the skills from one course into a different discipline area. In an attempt to improve the effectiveness of schooling, curriculum reforms have been regularly introduced. Integrating or infusing mathematics in a science class is a curriculum strategy that is aligned with the goals of the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices, 2010), as well as the *Next Generation Science Standards* (NGSS Lead States, 2013, 2014). If infusion positively affects learning, an improvement in student achievement and attitudes toward integration will be noted. This study analyzed empirical evidence to assess STEM learning through integration; such evidence is necessary to support

replication and expansion of this instructional model in middle and high school classrooms. In terms of the research framework, the outcomes were based on student learning and achievement as well as student and teacher attitudes.

## Chapter 2

### Literature Review

#### 2.1 Introduction

In American education, school curricula have traditionally been based on the concept that disciplines should be taught in distinct and separate classes to facilitate understanding. Despite many educational reforms over the history of public schooling in the United States, teaching methods in mathematics and science have oscillated between content-driven and student-centered approaches (Sanders, 2008). Many curricula present knowledge and skills in segmented and isolated fragments. This has left little opportunity for students to understand concepts in a larger context (Meyer, Dekker, & Querelle, 2001).

In order to establish a research-based foundation for the current study, this chapter will provide a review of the literature including the conceptual framework (Section 2.2), an historical perspective of integration (Section 2.3), views from professional organizations espousing the value of integration and the recurring call for more rigorous empirical data collection (Section 2.4). Related critical issues include the lack of an operational definition (Section 2.5) and practical challenges to integration (Section 2.6). These will be discussed to provide an understanding of how to foster implementation in the classroom, which is essential in evaluating an integrative curriculum. Results of implementation in various educational settings are evaluated (Section 2.7). The chapter concludes with a summary of relevant prior research (Section 2.8). The research study documented in this paper builds upon science education literature through a newly developed conceptual framework, described below.

## 2.2 Conceptual Framework

The conceptual framework that guided this research was synthesized from three different perspectives that support the implementation of integrated mathematics and science curricula. First, the National Research Council recommended science and mathematics integration to improve student learning and interest in STEM fields (National Research Council, 2011, 2013). Numerous studies provided empirical support for these policy guidelines. Secondly, Berlin and White formulated an interpretive theory for essential components of integration development (1993, 1994, 1995, 2001), identifying connections between programmatic design and optimal student outcomes. Third, the National Academy of Sciences (2014) proposed a research framework connecting ideal curricular characteristics and needed areas of assessment. The resulting theoretical framework provided the rationale and strategy for enacting integrated STEM curricula to maximize student and teacher impacts and to measure associated outcomes.

Numerous recent reports have recommended the integration of mathematics and science in STEM educational reforms (AAAS, 1989, 1993; National Research Council, 2011, 2012). Why is mathematics and science integration essential for today's students? An integrated curriculum is a means by which students can acquire scientific concepts by developing organizational knowledge structures and making connections among ideas in social settings (AAAS, 1989, 1993; Cohen, 1995; Driver, Asoko, Leach, Scott, & Mortimer, 1994). Such student-centered, less fragmented experiences have provided stimuli that improve problem solving and higher level thinking skills (Barab & Landa, 1997; Furner & Kumar, 2007; King & Wiseman, 2001; Smith & Karr-Kidwell, 2000). Teaching STEM disciplines in an integrated fashion often facilitates quantitative literacy (Wilkins, 2000) and allows students to recognize



their relevance, particularly when presented in authentic, real world contexts (Venville, Wallace, Rennie, & Malone, 2000).

Previous studies indicate that curricular approaches that implement rigorous integrative strategies tend to result in increased student achievement and STEM interest (Barcelona, 2014; Hill, 2002; Judson & Sawada, 2000; Riskowski, Todd, Wee, Dark, & Harbor, 2009). This is an important consideration for middle school learners, since interest in science has been shown to decrease as students advance through middle and high school (National Research Council, 2011). Achievement and interest are leading indicators of student intentions to pursue post-secondary STEM study and careers (Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006), so instructional approaches that improve students' performance and attitudes show promise for expanding the STEM pipeline.

The conceptual framework for this research was also based upon numerous studies of Berlin and White (1993, 1994, 1995, 2001, 2010). Their studies suggested that integration is more than just the learning of each discipline's objectives; when mathematics and science are taught together, students develop problem solving and process skills on a much higher order than when the two disciplines are taught independently. This added value of integration is also part of the rationale for current educational standards such as *Next Generation Science Standards* (NGSS Lead States, 2013) and the *Common Core State Standards for Mathematics* (National Governors Association and Chief Council of State School Officers, 2010).

Berlin and White (1993, 1994, 1995) presented a model to assist in the development of an integrated lesson. These authors proposed the *Berlin-White Integrated Science and Mathematics Model* (BWISM), an interpretive theory designed to suggest best practices. This model identified six aspects of the integration of science and mathematics to serve as a template to delineate

important instructional characteristics. Each aspect is summarized below (Berlin & White, 1993):

1. *Ways of learning.* Students must be actively engaged in science and mathematics learning. A constructivist approach will allow students to organize their thinking to make sense of both disciplines in a mutually reinforcing learning process.
2. *Ways of knowing.* Students will employ both inductive and deductive reasoning in understanding science and mathematics. They will identify patterns through a qualitative approach (inductive) and apply what they have learned to new situations in a quantitative approach (deductive).
3. *Process and thinking skills.* Integrated mathematics and science can promote higher order thinking skills, such as organizing data, developing models, graphing, and interpreting data.
4. *Content knowledge.* Concurrent themes can be found in both science and mathematics, for example, the exchange of energy and quantitative expression of rate of change (slope).
5. *Attitudes and perceptions.* Students' beliefs about integration will influence their ability and confidence to reason logically, for example, basing decisions on the interpretation of data.
6. *Teaching strategies.* Science and mathematics integration will incorporate a range of cross-disciplinary knowledge and ample opportunities for students to understand connections and be assessed on their ability to do so.

The authors asserted that various combinations of these elements would be useful in integrating science and mathematics effectively. They stated that although these components are not exclusive to the teaching of science and mathematics, they provide a conceptual base for designing an integrative curriculum with operational terms that may guide empirical study. Although Berlin & Lee (2005) noted that just 17% of publications on science and mathematics integration since 1991 have been empirical research, they did not specify how educational researchers might provide data to enrich the knowledge base in the field. The present study provided such data to assess the programmatic impacts of mathematics and science integration.

St. Clair and Hough's (1992) review of the research reinforced this framework, summarizing that a curriculum should focus on a topic from different perspectives, e.g., mathematics and science, so that students are exposed to the skills needed to construct understanding and strengthen the process of problem solving. In addition, cognitive research has suggested that people process information through patterns and connections rather than fragmented bits (Ausubel, Novak, & Hanesian, 1978; Cohen, 1995). This is similar to the constructivist theory that states that students build new knowledge and deepen understanding by making connections between their previously learned ideas and new experiences, therefore meaningful learning occurs when students have a context for organizing abstract understandings of science and mathematics (Bransford et al., 2000; Frykholm & Glasson, 2005).

The National Research Council of the National Academies provided an analytical framework for measuring programmatic impacts in *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research* (2014). This report concluded that integration must have intentional support for students to build their knowledge in multiple disciplines. This support may come from improving the expertise of educators through collaborative training; in this way, their disciplinary knowledge and confidence will contribute to their effectiveness. Their assessments must be designed to go beyond recall of content knowledge and have students apply their skills to solve problems. This report also acknowledged the limited amount of empirical studies on STEM integration and associated professional development, as well as the small sample sizes, providing further justification for the present study (see also Loucks-Horsley & Matsumoto, 1999).

Figure 1 (below) summarizes the conceptual framework, synthesized in terms of the potential benefits of mathematics and science integration, principal components of project

enactment, and measuring programmatic impacts. These dimensions illustrate the rationale for why STEM curricula should be integrated, the logistics of how to do so effectively, and ways to provide evidence of success and reasons for project replication. In doing so, students might improve their science learning and attitudes towards STEM at a pivotal point in their academic lives, and teachers might gain the knowledge and skills to guide their students towards these goals.

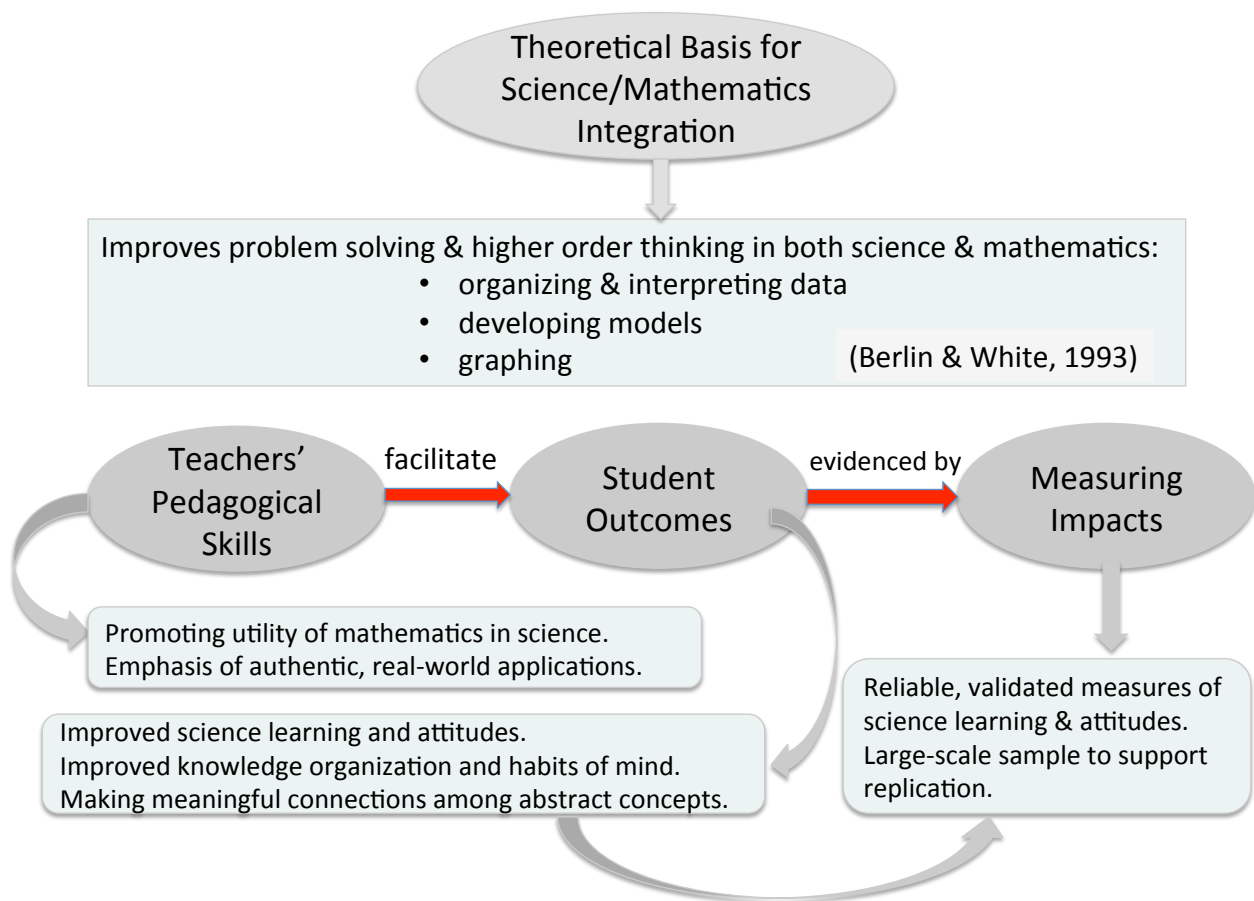


Figure 1. Science and mathematics integration: Conceptual framework.

### 2.3 History of Science and Mathematics Education

Since the beginning of public schooling in America, education has continually undergone evaluation and reform. From the perspective of science curricula, recommendations for teaching have included an emphasis on scientific knowledge, skills for employment, social awareness, and citizenship. The frameworks of national standards and benchmarks have enhanced the development of science curricula throughout U.S. history. Several trends have particular relevance for the construct of science and mathematics integration. A review of the history of science education reforms is useful to show how cultural and historical events have impacted the relationship of the current standards to integration.

In 1892, a conference of educators was assembled to attempt to provide structure to American high school education. This assembly, known as the Committee of Ten, proposed uniform courses of study necessary for high school graduation. This meeting included four subcommittees in various disciplines including mathematics and science (National Education Association, 1893). Although the Science Committee members were aware of the importance of mathematics as it related to science study, even suggesting a sequence of science courses based upon mathematics pre- or co-requisites, the Mathematics and Science Committees never met together and the shared content of each course was never discussed. Consequently, science and mathematics courses during this era were taught as distinct disciplines.

*The Cardinal Principles of Secondary Education*, published by the Commission on the Reorganization of Secondary Education (CRSE) (National Education Association, 1918) twenty-five years after the Committee of Ten's report, suggested schools should teach curricula that are socially relevant to students and guided by potential future educational and vocational outcomes. Whereas the Committee of Ten advocated that all students, regardless of their future pursuits,

should be taught all the same courses with the same level of rigor, *The Cardinal Principles of Secondary Education* were an attempt to meet the individual educational needs of all students. The CRSE identified seven objectives (Health, Command of Fundamental Processes, Worthy Home Membership, Vocation, Citizenship, Worthy Use of Leisure, Ethical Character) that were not to be taught as separate areas of study but as interrelated topics.

Since then, several attempts have been made to integrate curricula in a more holistic manner. John Dewey (1919, 1938) in the 1920s and 30s led the “Progressive Education Movement,” in which a student’s education was grounded in social issues and knowledge would be organized around relevant themes. Dewey emphasized the need for teachers to unify student learning rather than enact a compartmentalized approach. Subsequently, the educational term “integration” was coined in *Education Index* in 1936 (as noted in Beane, 1996), and reflected the work of educators who had advocated for an alternative to the traditional separate discipline approach.

During the Sputnik era, with input from professional scientists and mathematicians, many classroom activities integrated science and mathematics. These integrated activities have continued in only a few undergraduate teacher education programs and professional development workshops (Bybee, 1997). The decade after Sputnik was known for its “alphabet soup” elementary science programs. The alphabet soup era was named for the acronyms of the three lead programs: *Science a Process Approach* (SAPA), *Science Curriculum Improvement Study* (SCIS), and *Elementary Science Study* (ESS). These programs incorporated mathematical skills and were more quantitative than qualitative. Emphasis was placed upon student observation, careful measurement, and performing appropriate calculations to reach conclusions and develop scientific understandings. Examples of these successful programs were the *Minnesota*

*Mathematics and Science Project* (Rosenbloom, 1963), the *Unified Science and Mathematics for Elementary Schools Project* (Sampson, 1977), *Great Explorations in Math and Science Project* (GEMS) (Lawrence Hall of Science, 1984) and *Activities that Integrate Mathematics and Science* (AIMS Educational Foundation, 1986). Although studies of these programs have shown they were successful in terms of elementary level student science performance, science was not taught in an integrated format in the middle and high schools.

In the late 1970s, Howard Goldberg, a physicist at the University of Illinois at Chicago, was discouraged by the lack of science homework assigned to his elementary school aged daughter. Reviewing prior projects, Goldberg developed a framework that streamlined the scientific method to make it more accessible to children. He developed laboratory investigations within a simplified context (Goldberg & Boulanger, 1981). In 1985, Goldberg and other science educators developed the *Teaching Integrated Mathematics and Science* (TIMS) curriculum (TIMS, 2004). The impetus behind TIMS was the desire to teach science to children in a way that reflected the practice of scientists. Modern science is essentially quantitative, and the TIMS curriculum was intended to make mathematics more meaningful to children by applying it to scientific contexts (Isaacs, Wagreich, & Gartzman, 1997). Although studies evaluating the effectiveness of TIMS showed positive student outcomes in mathematics, schools failed to continue the curriculum. This was attributed to teacher turnover and the large investment of professional development to support its implementation (Goldberg, 1993).

The mid to late 1980s saw little innovation and somewhat of a decline in science education. Although the amount of science coursework required to graduate increased as a result of the publication of *A Nation at Risk* (National Commission of Excellence in Education, 1983), the passage of NCLB (2001) only mandated that schools test student achievement annually in

mathematics and English, resulting in school resources being directed towards these disciplines and leaving science, at all levels, to fall by the wayside (Jennings & Rentner, 2006; Southerland, Smith, Sowell, & Kittleson, 2007). Science courses reverted to being theory based and more discipline oriented and were not connected to other disciplines. Researchers have argued that delineating content in this manner is inconsistent with students' lived experiences (Lederman & Niess, 1997).

## **2.4 Current Trends and Policy Positions**

Currently, curriculum integration is now the cornerstone of efforts aimed at reforming education to focus on the needs of students in modern society. When compared to international peers, the performance of American students does not match the status of the nation's leadership position in scientific innovation (Kuenzi, 2008; National Academy of Sciences, 2007). The preparation of American students in science and mathematics has often failed to reach a sufficient level to support the rapidly expanding technological workforce. The *Trends in International Mathematics and Science Study* (TIMSS) (Mullis, Martin, & Foy, 2008) reported that American students have been performing at a lower level than their global peers in mathematics yet higher in science. U.S. eighth grade students performed significantly lower than international comparison groups in mathematics, with an average score of 500 compared to the mean of 513; in science, U.S. eighth graders fare better, scoring 534 compared to the mean of 516 (National Center for Education Statistics [NCES], 2000). However, at the end of twelfth grade, American students scored nearly last among students in industrialized countries in both science and mathematics (NCES, 1998).



Finland has consistently performed above its international peers on the Program for International Student Assessment (PISA) international exams (Organization for European Cooperation and Development, 2001). Research has attributed Finland's success to many factors including high respect for teachers that include professional teacher training, learner-centered classrooms where students work collaboratively on projects that cut across traditional disciplinary lines and a minimum of standardized testing (Paine & Schleicher, 2011). Based on this evidence, and students' need for college and career readiness, the current national science and mathematics standards that guide state curricular frameworks and local courses of study have affirmed the importance of integrating science and mathematics (National Governors Association and Chief Council of State School Officers, 2010; NGSS Lead States, 2013).

In the last few decades, formal positions have been taken by national educational organizations to integrate science and mathematics curricula. The National Science Teachers Association (NSTA) recommended that science should be integrated with teacher support to incorporate a variety of assessment methods (NSTA, 2003). The National Council of Teachers of Mathematics (NCTM) emphasized that although not all mathematics can or should be taught in an integrative fashion, mathematics experiences at all school levels, especially in grades 5-8, should include opportunities to learn about mathematics by working on problems arising in contexts outside of mathematics. These connections can be to other disciplines as well as to students' daily lives (NCTM, 1991, 2000).

The National Research Council suggested that elementary students should learn mathematics and science in an inquiry-based setting and teachers should emphasize connections between the disciplines in order to facilitate students' understanding of both topics (National Research Council, 1989). The emphasis on mathematics-science integration goals by national

educational organizations has not diminished in recent years. *Benchmarks for Science Literacy*, while acknowledging the uniqueness of each discipline, suggested there be more of a relationship among science, mathematics, and technology because each is dependent upon and supports the others (AAAS, 1993). Other AAAS Project 2061 publications (1989, 1993) suggested that an integrated mathematics-science curriculum might facilitate students' abilities to apply STEM concepts in new situations.

The opportunity for students to experience mathematics in 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 of science can model an approach to problem solving that can be replicated in the study of mathematics (NCTM, 2000).

In addition to STEM policy organizations, commercial groups in the U.S have endorsed the push for mathematics and science integration (Change the Equation, 2015; National Academy of Sciences, 2003). The Industrial Research Institute (IRI) is a nonprofit organization of 235 leading industrial companies in fields such as aerospace, automotive, chemical, computer, and electronics. IRI's mission is to enhance technological innovation in industry by supporting high-quality mathematics and science education. The benefits include a more qualified workforce and a public that is able to make informed decisions regarding the development and use of science and technology. To that end, IRI advocates for the use of a national standards curriculum that develops and supports the use of integrated teaching methods for science and mathematics (National Academy of Sciences, 2003).

The push to integrate has been reiterated by more recent educational reforms. The newly published NGSS (NGSS Lead States, 2013) identified one of its five key ideas as “crosscutting”

concepts. Crosscutting concepts provide students with opportunities to experience connections across different disciplinary content. The push for this crosscutting approach is to present science content in a manner that is more representative of how scientists actually work. Science concepts that consist of a mathematical perspective include recognizing patterns, understanding scale, proportion and quantity, and identifying relationships among variables (National Research Council, 2012, 2013).

In addition, the recently developed CCSS emphasize mathematics in a students' course of study. The standards call for students to understand scientific ideas in situations that require mathematical knowledge. Correctly applying mathematical knowledge depends on students having a solid conceptual understanding of reasoning abstractly and quantitatively, modeling with mathematics, and strategically using appropriate mathematical tools (National Governors Association Center for Best Practices and Chief Council of State School Officers, 2010). Currently, the NGSS publisher, Achieve, has assembled a group of educators to develop tasks that combine NGSS and the CCSS in mathematics and has begun to publish these integrated lessons for broad adoption (NGSS Lead States, 2014). Focusing on application and mathematics-science performance skills, these tasks pull together the big ideas of NGSS and the CCSS. These sample lessons provide models that highlight the opportunities to integrate mathematics and science in order to support a shift in current pedagogy. In addition, new assessments are being created to address the increased rigor of middle school science exams that have an emphasis on mathematical process skills and scientific habits of mind (AAAS, 2015; Edinformatics, 2015; NGSS Lead States, 2015).

## 2.5 Definitions of Integration

**Ambiguous terms.** One possible explanation for the lack of empirical research on mathematics and science integration is a conceptual issue related to the definition of integration (Berlin & White, 1995; Stinson, Harkness, Meyer, & Stallworth, 2009). Upon examination of the literature, it is apparent that no universal and commonly understood term is utilized to describe integration. The lack of a clear definition of terms makes it difficult to formulate valid comparisons between studies (Lederman & Niess, 1997). As Davison, Miller, and Metheny (1995) wrote:

Few educators would argue about the need for an interwoven, cross-disciplinary curriculum, but to many, the nature of the integration in many interdisciplinary projects is not readily apparent. A more pervasive problem is that integration means different things to different educators (p. 226).

This confusion has been evident in the multiple keywords used to describe this type of curriculum. Besides integration, other terms have included, but were not limited to: interdisciplinary, multidisciplinary, thematic, coordinated, connected, nested, embedded, threaded, immersed and infused. Lonning, DeFranco, and Weinland (1998) further described integration by defining their own terminology in relation to integration. This terminology provides a more specific reference frame for true integration as opposed to a cursory combination of discipline-specific language. The following is a summation of their terms:

- *Theme* - a topic or concept that provides the focal point and guides the implementation of an interrelated series of lessons or activities.
- *Interdisciplinary* - utilizes methods and language from more than one discipline and applies it across the curriculum to a central theme.
- *Integrated* - the relationship between two or more disciplines, which are included in an interdisciplinary unit.

The *Framework for K-12 Science Education* incorporated the notion of integration in their definition of crosscutting concepts, which they defined as “concepts that bridge disciplinary boundaries, having explanatory value... these concepts help provide students with an organizational framework for connecting knowledge from various disciplines into a coherent and scientifically based view of the world” (National Research Council, 2012, p. 83). Several of the defined crosscutting concepts directly integrate mathematics and science, for example, “*Scale, Proportion, and Quantity*,” “*Cause and Effect: Mechanism and Explanation*,” and “*Patterns*.” The interdisciplinary approach embedded in NGSS has garnered significant support despite inconsistent terminology in describing associated practices. The *Framework* also emphasized the need for instructional support in providing connective structures for students to make sense of concepts applied to multiple disciplines.

In an attempt to illustrate these definitions, topics taught in a middle school curriculum will be described hypothetically in terms of how they would fit into each of the categories. A middle school thematic unit could be centered on food and nutrition. In science, different molecules in food and the digestive body system could be taught. Social Studies can speak to the economics of an agricultural society and subsidized farming, and Health and Physical Education can address body image and healthy diets and exercise. The theme is carried over to different disciplines but the learning outcomes are different in each discipline. However, in interdisciplinary curricula, the learning objectives are the same and span across two or more disciplines within a cohesive range of representations (Nathan et al., 2013). Simple machines, for example, can be taught simultaneously in science and technology and both classes have the same learning objectives, such as the ability to apply conservation of energy to physical systems through proportional reasoning. Lastly, an integrated curriculum is one in which two or more

disciplines are taught in the same classroom, complementary to each other. However, even with these examples, the definitions are still somewhat ambiguous. A cursory look at sample lesson plans show that the words “interdisciplinary” and “thematic” are often used interchangeably or even simultaneously.

As previously mentioned, for purposes of this research study, when speaking of integration in terms of the MiSP Project, the word *infusion* will be used. The working definition of infusion is addressing important concepts in one discipline within the context of the predominant discipline taught in the classroom, specifically in this study, mathematics being infused into the science classroom.

**Operational framework: Models for interpreting integration.** Another debate among educators has been qualifying what makes a lesson truly integrated. In Berlin and White (2001), they describe five categories as presented at the 1967 Cambridge Conference on Integration of Mathematics and Science Education to define a particular mathematics or science lesson:

1. Math for Math
2. Math for Science
3. Math and Science
4. Science for Math
5. Science for Science

Since these categories have also been open to interpretation, Lonning and DeFranco (1997) constructed a visual continuum to clarify these categories (summarized in Figure 2). True integration of mathematics and science has been found at the center point of the continuum, yet only the two opposite ends of the spectrum have been seen consistently in American education programs.

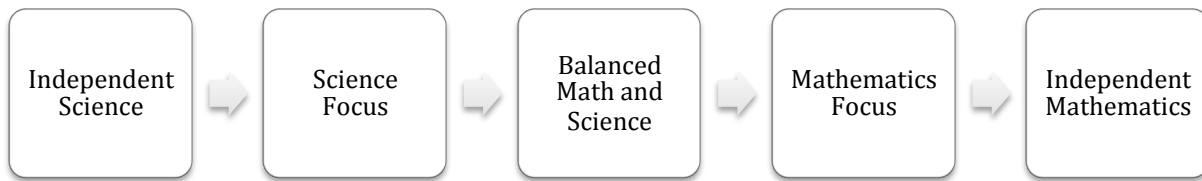


Figure 2. Continuum of science and mathematics (adapted from Lonning & DeFranco, 1997).

Again, in the researcher's attempt to clarify the continuum, examples from a typical middle school curriculum are suggested. At one end of the spectrum starting from the left, *Independent Science* is where no mathematics is used to support a topic like global warming. Instead only greenhouse gases and human impact would be discussed without any mathematical data support or analysis. Moving to the right is *Science Focus*. In this category mathematics is used as a tool for interpreting data. A middle school example of this would be to compute the average of numbers after a certain number of trials. In the middle of the continuum is what educators perceive as true integration or *Balanced Math and Science*. Using the global warming topic, lessons would involve data such as the amount of Arctic ice extent or the amount of atmospheric carbon dioxide from reputable science websites. Continuing to the right is *Math Focus*. This would use mathematical problems with science content but no in-depth science explanation, such as a velocity problem. At the opposite end of the continuum is *Independent Math*, which would consist of problems that do not have a direct application to science.

The authors then presented an interpretive framework to help in the development of an integrated unit. They used a flow chart to evaluate their model of an interdisciplinary and integrated (I/I) curriculum. The model is designed with the idea that each lesson should be written with a team of teachers from each of the content areas that would be addressed in the

lesson. The authors ended with a description of the process of creating an I/I lesson using an elementary school theme of mapping.

Although the authors believed they were streamlining the ability to create an integrated lesson, the flow chart was not easily understandable and this ambiguity has limited its usefulness in current educational settings. The I/I lesson on maps worked well for integrating science, social studies and mathematical components that were based on the school's learning objectives. This is a key step in the validity portion of the flow chart. The paper's main purpose was to give educators a model to construct I/I lessons that were relevant and grounded in curriculum and did concede that finding an interdisciplinary theme was sometimes the "pitfall" of designing an integrated lesson.

Similarly, Miller, Metheny and Davison (1997) identified five approaches to integration: discipline specific, content specific, process, thematic and methodological integration. *Discipline specific* integrated two branches of the same discipline, for example, a mathematics activity that integrates algebra and statistics. *Content specific* involved choosing existing learning objectives from mathematics and science and combining the two objectives, such as using mathematical graphing skills during an ecology unit in science. *Process integration* involved students utilizing science and mathematical process skills such as communicating, classifying and interpreting data in real life activities, for example, advocating for recycling. *Thematic approach* involved multiple disciplines teaching the same topic from a different prospective, for example, studying about marine biology in different classes at the same time. *Methodological integration* involved using science methodology to teach mathematics. Such methodologies included inquiry labs with mathematical applications. Both the Lonning et al. (1998) and Miller et al. (1997) papers did not advocate for any specific type of integration over another.



Vars (1991) evaluated integrative, or holistic, curriculum including core curriculum. Core curriculum, in this context, focused on student issues and their society. This core curriculum concept has its roots in the 1800s and saw several attempts over the years to take root, particularly in the 1930s and 40s, when the progressive education movement included a strong emphasis on student-centered integrative approaches to education. Vars reviewed multiple studies on the effectiveness of integration and found that in nearly all of the programs students performed as well or better on standardized tests than students enrolled in traditional separate discipline specific curriculum. Based on his review of these studies and his support of their outcomes, he suggested that true integrated curricula must consist of solid content matter along with the interests of the student. Vars acknowledged that this type of lesson requires multiple levels of school staff cooperation to achieve complete integration.

These previously mentioned studies emphasized two critical criteria for defining integration. Integration implies unity and a holistic approach rather than separation and fragmentation, and students need to develop integrated skills from personally meaningful questions that build upon their own experiences (Beane, 1991; Smith & Karr-Kidwell, 2000). When charged with the task of creating an integrated lesson, some of the above definitions and frameworks are helpful, but there appears to be instances where one of the components has not been a natural fit with the learning objectives, and teachers used integration as a change of pace rather than as a conscious effort to connect the two disciplines (Miller & Davison, 1999). Some models have been proposed to achieve balance among mathematics and science content knowledge, the process of teaching and learning, and measurement and assessment (Huntly, 1998, 1999; Kiray, Gok, Caliskan, & Kaptan, 2008; Kiray & Kaptan, 2012). Other recent models encouraged the use of correlations to standards as a way to assist teachers in recognizing

opportunities for integration (Koirala & Bowman, 2003; West, Vasquez-Mireles, & Coker, 2006). Providing more tangible connections, recent integrated curriculum manuals have been published which reference both the science and mathematics standards that are applicable to the particular lesson (Eichenger, 2005; Mason, Mittag, & Taylor, 2003; Sherrod et al., 2009).

The issue then is how to develop a coherent curriculum to promote integrated teaching. Using the above-mentioned continuum, flow charts or BWISM model may help in clarifying or fine-tuning a science-mathematics integrated lesson, however, the main consideration must be the connection between the science content and grade-appropriate mathematics skills needed to solve relevant science problems. Zemelman, Daniels, and Hyde (2005) identified several practices to teach an integrative mathematics and science curriculum. These included the use of inquiry, questioning strategies, and having students make conjectures and apply problem-solving skills. An inquiry paradigm has also been strongly supported by Furner and Kumar (2007), who suggested the curriculum should be based on problem solving that requires the use of both mathematics and science. These types of problems should be authentic and engaging. Similarly, rich and engaging mathematical tasks were identified in *The Professional Standards for Teaching Mathematics* as those that deal with problem solving and mathematical reasoning while encouraging the student to develop a comprehensive connection to mathematical ideas (NCTM, 1991).

## **2.6 Integration Challenges**

Challenges to integration have been well documented. They include inadequate curriculum materials, insufficient pre-service and in-service training (Lehman & McDonald, 1988), lack of support from administrators, especially in accommodating shared common planning periods with the mathematics and science departments (Vars, 1991), and lack of teacher

advocacy in stressing the value of integration. This resistance by teachers may be due to lack of confidence in teaching an integrated curriculum (Pang & Good, 2000), and/or time constraints due to already aggressive curriculum requirements (James, Lamb, Householder, & Bailey, 2000).

**Curriculum development.** One program that addressed some of these deficiencies was the *I<sup>3</sup> Project* (Watts, 2005), a professional development program that was implemented at the University of Louisiana at Monroe, which hoped to provide teachers with insights into scientific inquiry and to provide materials and support for integrating science, mathematics and language arts instruction. Using anecdotal evidence, this study evaluated a professional development program in inquiry. Teams were formed consisting of a science teacher, mathematics teacher and a language arts teacher joined by a pre-service teacher from the university. The teams met for two weekend sessions and then continued professional development with mentors during a summer institute. Based upon interest, the teams worked with the mentors on inquiry-based projects. At the end of the summer session the teams presented the lessons they prepared during their projects.

The author stated that the instructional goal of creating inquiry-based lessons was realized. Additional goals of increasing inquiry skills with seasoned teachers while working collaboratively with pre-service teachers were also achieved. A final positive outcome was the development of a relationship between secondary school teachers and the mentoring scientists from the university. Although it was a worthwhile endeavor to match high school teachers with a mentor at a university to create integrative lessons, there was no evidence of whether teachers actually implemented these lessons in their classes and if they did, whether they were successful in improving student achievement.

*Coming Full Circuit, An Integrated Unit Plan for Intermediate and Middle Grade*

*Students* (Sandman, Weber, Czerniak, & Ahern, 1999) described another program designed to help create materials for integrated lessons. The authors evaluated the *PRISM CLASS* (Project Integrating Science and Math with Language Arts and Social Studies) funded by an Eisenhower Professional Development Grant. The program was created by four university faculty members for in-service and pre-service teachers. During a summer workshop both groups refined their mathematics and science content knowledge and pedagogical skills. They also played the role of students in an integrated lesson developed by the university faculty. The student teachers and classroom teachers were then asked to create a 10-day integrated unit that they would implement the following fall and evaluate the effectiveness of the lesson with a rubric.

The lesson presented at the summer workshop focused on electricity. Participants learned about circuits, conductors, insulators and switches and then had to assemble a simple circuit themselves. Studying Leonard Euler's mathematical work on circuits, the student teachers made connections between electricity and mathematics. Other mathematical activities involved the Konigsberg bridges, a mathematics problem exploring whether citizens of Konigsberg, Russia, could traverse the city utilizing each of the city's 7 bridges without crossing over any of them twice. To solve this problem the teachers learned to make paths, which in turn were compared to circuits. The participants then used this information to design efficient plans for tasks such as snow plowing city streets or making deliveries. This added the real life component suggested above by Beane (1997) for successful integration.

As a final project the participants had to make a lunch box alarm. During the activities, participants commented on how the disciplines were indistinguishable from each other. Immersing themselves as students, the participants now had an understanding of how to create

their own thematic integrated unit. The researchers concluded that because the teacher participants were visibly excited during the lunch box alarm activity this would transfer to their enthusiasm to teach integration. Again, even though the teachers did achieve the goal of creating an integrated lesson, this paper did not report whether continued implementation took place in the classroom, and no student effects were documented.

James et al. (2000) researched the effectiveness of *Project GTECH* (a project funded by GTE) to provide integrated instructional materials. Project goals were to develop multimedia instruction to integrate science, mathematics and technology; to involve teachers and students in lesson development; and to field test and revise materials as needed. To accomplish these goals, nine schools were selected with teams of mathematics, science and technology teachers, while enlisting the support of the school principal. A planning team consisting of university faculty was formed to help with professional development of these teachers. Participating teams were asked to help develop and field-test the lessons. The teachers participated in a training program during the academic year and over the summer. The planning team went out on several occasions to make observations and monitor the implementation of these lessons, particularly the technology component. The result of this program was that 7 of the 9 teams developed integrated lessons using a specified computer program. The teachers within the schools worked collaboratively and were able to instruct students in this technology. These trained students were then able to assist other students as well as additional staff. The program was so successful that an elective course was created known as the *GTECH* course.

The authors concluded that teachers who learned the technology component through the *GTECH* program continued to use computers in their lessons. On the downside, even though the lessons integrated science and technology, the mathematics component was weak due to lack of

support from the mathematics teachers. The standardized mathematics assessments were weighted more heavily than the science assessments in this research location. Consequently, the mathematics teachers were not willing to give up time to teach the integrated lessons as they felt they needed to devote this time to test preparation. In addition, although students became peer tutors, it is unclear as to whether these newly acquired technology skills assisted the students in achieving the science and mathematics learning objectives. Other research has emphasized the need to measure learning outcomes specific to individual disciplines when planning and implementing interdisciplinary units (Ross & Hogaboan-Gray, 1998).

**Pre-service training in STEM integration.** Another challenge mentioned is the lack of training and support for pre- and in-service teachers, cited by policy makers as a critical component of preparing and inspiring students to pursue STEM study and careers (National Research Council, 2012; PCAST, 2010). Furthermore, if mathematics and science teachers are to apply true integration, knowledge of the other's content is essential (Kurt & Pehlivan, 2013). Innovations in the pre-service training of mathematics and science teachers have been shown to help them recognize the relationship between the two disciplines (Berlin & White, 2010; Furner & Kumar, 2007; Koirala & Bowman, 2003; Meisel, 2005; Wang, Moore, Roehrig, & Park, 2011). Currently, most pre-service science and mathematics methods courses are taught separately and as a result new teachers are not prepared to deliver an integrated lesson (Frykholm, & Glasson, 2005; Hurley, 2001; Kurt & Pehlivan, 2013). New teachers must create an environment that has an emphasis on critical thought, problem solving and applications to the real world (Horak, 2006). Mathematics students should be involved in hands-on or inquiry-type approaches just as they are in science classes (Dolgos & Elias, 1996). If an integrated topic allows students to perform science experiments in mathematics classes, it will take more

instructional time and involve different classroom management skills not typically applied in traditional mathematics classes (McBride & Silverman, 1991).

Conte and Weber (1999) evaluated an NSF-funded study on pre-service training done at The College of New Jersey to determine whether technology helped students learn about mathematics and science. The project goals were to integrate the teaching of science, mathematics and technology; assist teachers in preparing female, minority and special education students to study and choose careers in mathematics, science and technology; and have the college serve as a resource for teachers to review or learn content. Teams of pre-service teachers (undergraduate and graduate students) joined with K-8 teachers to create Thematic Learning Units and then observations were made. The conclusions from the observations were that students exhibited a higher level of motivation due to the real world opportunities to apply mathematics to science principles. The lesson they highlighted involved building a robot arm that modeled an insect appendage. This project seemed to be unrelated to any science learning objectives, nullifying one of the science criteria used to assess the project's success. The mathematics and technology assessment was simply a report using key content words, and referencing one website used to research the paper. Neither the lesson nor the assessment was rigorous in terms of content standards. There was no indication of how problem solving within the group was assessed. Besides the anecdotal testimonials by the teachers regarding students' attitudes, there was no formal assessment supporting this integrated program. A more rigorous study would have measured student achievement and attitudes directly. However, increased student motivation from an integrative curriculum has been substantiated by numerous other studies (Cosentino, 2008; Hartzler, 2000; Hill, 2002; Ross & Hogaboan-Gray, 2002).

An integrated elementary mathematics and science pre-service methods course was implemented at Montana State University in Billings (Miller et al., 1997). To evaluate this program, pre-service teachers used journals as a way to evaluate the effectiveness of integration. Surveys were also used to evaluate pre-service teachers' attitudes towards teaching science and mathematics. From these surveys, heterogeneous groups were formed and these groups spent the semester investigating the different approaches to integration. Each group met after class and prepared lessons to share with the other groups. After each presentation, feedback was provided by students, the methods teacher, and other college faculty. At the end of the semester the pre-service teachers were asked to write their reflections in a journal. These comments were evaluated to determine the attitudes of pre-service teachers toward integration. The entries showed a positive view of integration and the student teachers conveyed confidence in their ability to integrate science and mathematics lessons. However, quotes taken from the journals did not indicate that pre-service teachers actually accomplished all the learning objectives; the authors suggested an improvement would be more peer coaching in the methods classes and modeling by faculty and local secondary teachers.

Frykholm and Glasson (2005) presented a model for pre-service teachers to experience lesson planning that made connections between mathematics and science, and reported the pre-service teachers' perceptions. The authors presented a conceptual framework for connecting science and mathematics. Within this framework they addressed the lack of consistency in terminology and advocated for the term "connections" rather than integration. They also addressed the lack of pedagogical content knowledge (PCK) as defined by Shulman (1986) as being an obstacle to planning and implementing integrative lessons. The authors designed a two yearlong methodology program where two different cohort groups were created around science



content. The groups were asked to develop a curriculum project that would connect science and mathematics. Discussions were recorded and researchers made observations. Participants responded in writing and orally to questions posed by researchers.

Results indicated the pre-service teachers felt connecting science and mathematics was necessary when planning lessons but most said they had not experienced these types of lessons themselves while secondary students nor had they learned how to plan integrated lessons in their own methods classes. The research from this program also suggested that since pre-service teachers' PCK knowledge is weak, they should take more science and mathematics content courses along with a collaborative methods course that enrolls both mathematics and science teachers simultaneously. These findings were consistent with researchers who have suggested pre-service teachers' content knowledge and pedagogical content knowledge must be improved to implement integration effectively (Kurt & Pehlivan, 2013).

**In-service training in STEM integration.** In-service training and professional development are often essential for the successful implementation of integrative STEM curricula, since this innovation is frequently piloted with existing teachers in the field. Research has shown that effective professional development has involved instruction in disciplinary content and assessment (Basista & Mathews, 2002; Borko & Putnam, 1996), intensive and sustained training by teacher educators and/or researchers (Supovitz & Turner, 2000), and teachers working in collaborative teams to plan integrative lessons and modules (Cantrell, Pekcan, Itani, & Valasquez-Bryant, 2006; Davis, 2003; Garet, Porter, Desimone, Birman, & Yoon, 2001). Teachers have valued explicit modeling of reformed pedagogical methods that mirror what their students may experience in the classroom (Desimone, Porter, Garet, Yoon, & Birman, 2002; Lewis, Baker, & Holding, 2015). Materials and resources provided in workshops should include

specific strategies for classroom enactment (Huntly, 1999; Schneider, Krajcik, & Blumenfeld, 2005). The following examples further describe characteristics of in-service programs to promote mathematics and science integration, with varying levels of success.

An in-service, school-university collaboration took place at the Boca Raton Community Middle School to address the training needed to implement an integrative curriculum (Kirkwood, 1999). Funded by the Florida Department of Education, the Boca Raton Middle School worked with the Department of Teacher Education at Florida Atlantic University. Teachers at the middle school consulted with University faculty to devise a thematic unit on the Caribbean, since many of their students were from Cuba, Haiti, Jamaica and the Dominican Republic. In science they studied the ocean ecosystem of the Caribbean and investigated plate tectonics. In mathematics, students converted from the English to the metric system and carried out a problem solving activity in which they quantified items needed for survival in a life raft. The results of assessments in mathematics and science showed some of the learning objectives realized but not all. Although the teachers asserted that they felt empowered by this curricular change and that they had addressed the needs of a multicultural student population, the assessment tools used did not strictly focus on the relationship between mathematics and science integration. For example, one of the mathematics assessments described was manipulating fractions in a recipe, while one science assessment was for student teams to construct a model to demonstrate the interrelationship between tectonics theory and volcanic activity. The study stated that it was difficult to assess individual students when they worked within their teams and that many of them had difficulty with each of the assessments. This weakness in the study suggests that further research is needed to explore individual student achievement with a validated assessment that has a direct connection between mathematics and science.

Clark and Ernst (2007) also reviewed a program that trained technology teachers in the ability to deliver an integrated lesson. The program suggested it was the technology class that was the driving force behind integration. They considered technology diverse enough to address skills in a variety of content areas. It was hypothesized that the technology teacher had the skillset that could then help students understand how technology works together with science and mathematics. This hypothesis turned out to be incorrect and the authors concluded that success of this program would require additional professional development and collaborative planning as well as a means of curriculum assessment.

**Administrative support.** Administrative support is another challenge documented in the literature related to integration and professional development (Johnson, 2006; Wong, 2004). The NSTA (2003) asserted that administrators play a key role in the quality of middle school science by providing opportunities for professional development, supporting adequate time for collaborative planning and dedicating necessary funding and resources for innovation. In the previously described study by Conte and Weber (1999), the authors highlighted the importance of the principal to the successful integration of curriculum. In schools with the principals' support, the project did well and unforeseen problems were solved by the administration. Satchwell & Loepp (2002) and others (Garet et al., 2001; Desimone et al., 2002) concluded that effectively integrated STEM curricula requires administrative and community support, concurrent with professional development that has been field-tested and provides feedback to teachers.

**Time considerations.** The preparation and subsequent implementation of integrated lessons requires a considerable amount of time invested on the part of educators. In the

previously described models of integration, many teachers across different disciplines planned the units together. In the ultimate student-centered integrated curriculum that has an unstructured core described by Vars (1991), teachers and students worked together to develop units of study, which is an additional investment in planning time. Other time considerations reported involved looking over both curricula to find possible areas of overlap and potentially altering the sequence of the topics taught in order to cover related concepts concurrently (NSTA, 2003).

**Summary.** Many of the authors concluded that effective integration of curriculum was dependent upon the principals' and other administrators' proactive and sustained support. Other factors that enabled integration were pre-service preparation, in-service training and professional development, the ability to plan with colleagues, and the need to embrace integration on a school wide level (McBride & Silverman 1991). In this way, integration methods may be shared, professional development can be more focused, and joint prep planning periods may be scheduled.

## **2.7 Case Studies of Successful Integration**

**Middle school settings.** Beane (1991) and Beane and Brodhagen (2001) suggested that middle school should be a general education school that focuses on concerns of the adolescent student and their society. They believed that teachers at this level should reduce content area barriers and relinquish their disciplinary specializations in order to provide a more integrative learning experience. Wieseman and Moscovici (2003) agreed with this idea and suggested that collaborating, while respecting each other's content expertise, is one way to effectively integrate science and mathematics. Many instructional STEM reforms have been targeted towards middle school students (Cantrell et al., 2006; Sandman et al., 1999; Satchwell & Loepp, 2002), with

most showing promising data to support widespread implementation of integration strategies. Within this perspective, several studies at the middle school level will be discussed.

In some middle schools, interdisciplinary teams are a basic organizational structure. A team generally consists of two to five teachers representing basic core discipline areas, which teach the same groups of students and have shared planning time (Arnold & Stevenson, 1998). Teaming lends itself to the type of integrated experience that Beane (1991) has advocated. Team structures have helped teachers transition into curriculum integration (Alexander, 2001). When teachers were responsible for more than one discipline, the boundaries between disciplines were broken down and this helped teachers recognize how disciplines may be integrated. However, although a team structure allowed for a higher rate of parental contact and a positive work environment, team philosophy and mission were often unclear and the use of planning time was often only marginally effective. Disciplines often continued to be taught separately during different class periods and curriculum integration was infrequent or nonexistent (Flowers, Mertens, & Mulhall, 1998).

Team size has also been a factor in team effectiveness. Typical five-teacher interdisciplinary teams include 120-140 students. Research has shown that teams of fewer than 90 students have more frequent and higher quality interactions among team members, and that these teams have made more curricular connections in their instruction (Flowers et al., 2000). Thus, when true curriculum integration has been a desired outcome, team size becomes an important consideration (Alexander, 1991; Arnold & Stevenson, 1998; Jackson, Davis, Abeel, & Bordonaro, 2000). Curriculum integration requires high levels of contact and communication among teachers and cooperation among students.

Russo, Hecht, Burghardt, Hacker, and Saxman (2011) researched a middle school integrated mathematics science and technology program. After attending workshops where the science teachers were trained in mathematics content, they worked with colleagues and university faculty to develop integrated lessons. Following the workshop the teachers implemented the lessons in their classes. The results of this program were obtained from teacher surveys, which indicated over 95% of students developed a deeper understanding of the mathematics covered in the lessons. In addition, 73% of teachers reported they were confident to highly confident in infusing mathematics into science and technology. Although this project addressed some of the challenges to integration mentioned above, namely, providing teacher training and the creation of integrated materials, it still did not provide robust data measuring student learning.

Venville, Rennie, and Wallace (2004) and Venville et al. (1998, 2000) performed studies that described integration success in terms of student engagement in middle schools in Western Australia. Interviews with teachers and school administrators along with classroom observation provided data for evaluating the curriculum's impact. A total of 36 teachers were interviewed from 16 schools. During observations, field notes were taken and samples of student work were analyzed. Observational data were used to confirm the interview data. The interviews described the various forms of integration used by the schools. Some examples were thematic and cross-curricular approaches, technology-based projects, extra-curricular competitions and community projects. Teachers felt students had a better understanding of mathematics and science concepts when applied to particular projects, but felt the students' depth of content understanding was not as strong. A limitation of this study was teachers' perceptions were used as a proxy for actual student performance. Similar limitations have cast doubt upon the rigor of many studies in

mathematics and science integration (National Research Council, 2014). However, the conclusion that integrated approaches to teaching tend to be more engaging for students has been reported by other researchers (Furner & Kumar, 2007).

**High school settings.** Examples of intuitive models of integrated curriculum have involved the study of physics with mathematics (Basok & Holyoak, 2007; Clayton, 1989; Redish, 2005; Zhou, 2005), chemistry and mathematics (O'Connor, 2003), and integrated mathematics and science with experimental inquiry (Wiltshire, 1997). One successful program took place in Appleby College High School in Toronto, Canada, where teachers used a physics course to naturally integrate science and mathematics in the context of empirical practice (Roth, 1992). A main attribute of this project was that students guided the lessons, and the teacher's intervention only occurred when there seemed to be an opportunity to develop a new skill. Because of their interest in race cars, students decided to investigate the effect of the shape of an object on velocity. The students used computer graphing applications and statistical programs to problem solve. They wrote lab reports, which included data analysis and interpretation of their results. This program was evaluated based on feedback from the students. The data sources for this feedback were student essays about their attitudes and surveys on the class environment. In addition, there was a group discussion with the students and their teacher. The response was overwhelmingly enthusiastic as students described enjoying the autonomy of working on authentic lab experiments with their peer group.

Roebuck and Warden (1998) presented two integrated lessons they had developed. The first lesson integrated mathematics with chemistry. The lesson would expose students to the scientific concept of radioactive decay and the mathematical concepts of exponential functions, probability, and graphing. These concepts were embedded within a mathematics and science rich

curriculum. The second lesson was *Efficiency in Nature*, which focused on the hexagonal shape of honeycombs. Kinesthetically, pennies were used to illustrate how circles are ineffective in being able to fit together without air spaces. Students would experiment independently with different shaped polygons to see which would be the best shape to build an efficient structure. This lesson also incorporated measuring angles. The science component not only addressed characteristics of the honeybee and its hive but also asked students to think critically about what effect this adaptation had on the honeybee's survival.

The authors concluded that these lessons provided true integration but acknowledged that only teachers who have an understanding of both mathematics and science can effectively implement these integrated lessons and readily convey these concepts to the students. The limitation of this study was that the lessons were not utilized in a traditional classroom setting, therefore, student understanding could not be assessed.

Wicklein and Schell (1995) also evaluated the effectiveness of multidisciplinary curricula. Four pilot high schools were studied in four different states in the Midwest. Each school established a multidisciplinary team consisting of science, mathematics and technology teachers, a school administrator and school counselor. Each team developed an integrated lesson that was individually evaluated through teacher-reported data, personal interviews, and on-site visits. In addition, students were provided an opportunity to discuss the pros and cons of the lessons. One of the locations in the study used an honors level biology course where students addressed science concepts through a research based problem-solving approach. Faculty members reported development of a positive collegial relationship among the participating staff. The principal of this school wrote that the greatest success of this program was the ability of the students to



realize the “applicability of several subject areas in solving science problems” (Wicklein & Schell, 1995, p. 64).

Another location described in the study focused on “at risk” ninth grade students and utilized an established integrated curriculum known as *Principles of Technology* (PT). This curriculum consisted of a two-hour block that integrated mathematics, science and technology and was led by a team of three teachers, one per discipline. Students received credit in both mathematics and science by taking this course. The teacher most knowledgeable in the topic led that segment of the curriculum - this enabled the other teachers to interact with the students providing additional help where needed. Students worked in small groups to solve various problems and were able to choose their own science research projects. Success in this school’s integration curriculum included improved motivation on the part of the students to attend class and the reduction of discipline problems. Students were described as having higher self-esteem, while teachers appreciated working collaboratively within an integrated curriculum.

In the third location, each of the team of three teachers (mathematics, science and technology) designed lessons that incorporated the other two disciplines. The teacher whose main discipline was being addressed that day taught the lesson. The goals for their lessons included interpreting mathematics and science principles and applying technology to solve natural and man-made problems. The greatest success of these integrated lessons came from the students’ ability to see the application of mathematics and science to solve problems.

At the final location discussed in this study, students with below average abilities in science and mathematics utilized a modified version of the PT curriculum mentioned above. The variation in delivering the PT curriculum in this school was that the students stayed in one classroom and the teachers rotated into each class as “experts” in their field. Following a

collaborative approach, students were sub-divided into four roles. Student role titles were supervisor, mathematics expert, technologist and laboratory technician. This approach allowed for cooperative learning and provided a real world model for solving problems.

Based on interviews and discussions with student participants, teachers, and administrators, Wicklein and Schell found that support of administration and a commitment by the teaching staff were the most integral components to the success of the program. Teachers said they felt empowered to positively influence students when working with colleagues to employ creative, integrated lessons. However, the authors suggested a limitation of their findings was the lack of a contextualized curriculum; an infused curriculum, such as the one utilized in this study, would have provided mathematics and science activities more readily applicable to everyday life.

**College settings.** Several studies have explored the impacts of integrated STEM curricula in university settings, emphasizing the importance of problem solving, cooperative learning, and evaluation of outcomes (Chauvot & Lee, 2015; Everett, Imbrie, & Morgan, 2000; Lee, Chauvot, Plankis, Vowell, & Culpepper, 2011). A study by Deeds, Allen, Callen & Wood (2000) explored the impact of a new mathematics and science curriculum introduced for all non-science majors. The course addressed the goals of college students learning about the connection between science and mathematics in their daily lives and increasing literacy in both disciplines. From surveys, the authors concluded that non-science majors were uninterested in mathematics or science because they had difficulty relating the information to the world around them and believed these courses were rote with just memorization of random facts.

The authors developed a new curriculum that stressed mathematics in the physical world, which took years to put into practice. It required the cooperation of multiple staff and the support

of the administration. Guest speakers such as Sheila Tobias, a well-regarded author supporting STEM integration (for example, Tobias, 1999), were enlisted to help promote the curriculum. She spoke to the students about how responsible citizens require a strong background in science and mathematics to inform decisions.

The integrated curriculum for non-science majors consisted of three courses: 1) *Mathematics and Inquiry*, 2) *Science and Inquiry*, and 3) *Undergraduate Research*. In the *Mathematics and Inquiry* course students worked collaboratively to learn traditional skills in trigonometry, statistics and calculus with the addition of oral presentations and written essays on the relevance of mathematics. The *Science and Inquiry* course was divided into three modules: The Nature of Science, Human Genetics and DNA, and Light and its Application. Lab experiments were incorporated into each unit. To strengthen understanding, students were divided into small groups and discussed books, current events and ethical issues related to science. The *Undergraduate Research* component allowed students to choose projects that had personal relevance. These included topics in diabetes and exercise and field studies in local ecosystems. Part of the success of these courses was attributed to the discussions of how mathematics and science were connected. As a result of this program, the science and mathematics division became a unified group of faculty that helped administer the courses collectively.

Another successful college program called *Symbiosis* coordinated an introductory biology course with statistics and calculus over 3 semesters. Students earned 6 credits while studying topics in population growth, public health, cell structure as well as others. Students in the course developed critical-thinking skills in context and had increased learning gains over the traditional freshman biology course (Depelteau, Joplin, Govett, Miller, & Seier, 2010).

## 2.8 Summary

Evidence about the success of integrated programs is conflicting, yet many insights can be gleaned from the review of literature. These insights are the foundation for the present study. A lack of consensus about the definition of integration makes it difficult to analyze programs systematically but mostly positive feedback was revealed through teacher testimonials and student attitudinal surveys. Of utmost importance, students valued mathematics and science integration and understood their interrelatedness, a major educational goal in middle school (NGSS Lead States, 2013). However, empirical research is needed to determine if these perceptions are correlated to academic success.

In summary, the studies discussed above expressed the following key points:

- The mathematics topic must fit naturally with the science lesson and the connections need to be made obvious to the student.
- Science lessons must allow for students to engage in hands-on activities using mathematical concepts.
- In-service and pre-service teachers must participate in professional development in both content and pedagogy to teach integrated lessons.
- Administrative support increased the success of an integrated program.
- Limited rigorous empirical studies have been done to determine student outcomes and the benefits of participating in an integrated program.

Criteria for successful integration were utilized in the current study, namely, training teachers to implement an integrated curriculum and providing teacher materials in a user-friendly format that identified the correlation between mathematics and science in inquiry-based laboratory activity lessons. In addition, this study examined programmatic impacts by administering and evaluating integrative assessments to measure science and mathematics achievement and attitudes towards science.

## **Chapter 3**

### **Methodology**

#### **3.1 Introduction**

This chapter outlines the research questions, the research design and methods, the assessments and survey instruments, and how data were analyzed. The aim of the study and research questions are stated (Section 3.2). An overview of the MiSP project with a program summary is provided (Section 3.3), along with the setting and study populations (Section 3.4). Instruments used for data collection are described and evidence of validity and reliability is documented (Section 3.5). Research design and analytical methods are explained (Section 3.6) and null hypotheses are proposed (Section 3.7). Limitations of the study (Section 3.8) are discussed. The chapter closes with implications of the results and contributions to science education research (Section 3.9) and a conclusion (Section 3.10).

#### **3.2 Aim and Research Questions**

This research is based upon a conceptual framework and review of literature that asserts mathematics and science may be integrated to support students' academic preparation for higher level learning and future careers. An aim of this study was to provide empirical data that may support the adoption of an integrative curriculum. As introduced in Chapter 1, the following research questions guided the study:

- Research Question 1: Have students' understandings of integrated science content improved as a result of the infused curriculum?

- Research Question 2: Have students' attitudes towards the relationship between mathematics and science changed as a result of participating in the infused curriculum?
- Research Question 3: How do students' views on integration correlate with their performance on an integrated science assessment?
- Research Question 4: How does teacher confidence relate to science learning outcomes and student attitudes?

It was hypothesized that students in an infusion class would have higher scores on the integrated content assessment and the lesson assessment when compared to students in a non-infused class. Also, there would be more positive associations with infusion in terms of confidence in ability and in the value of an infusion philosophy among the students involved in the treatment, and teachers' confidence would be positively correlated with improved student science performance.

### 3.3 MiSP Project

Since this research was based upon the established MiSP program (Hofstra University, 2000), an overview of the project and relevant findings are discussed. The primary mission of the MiSP program was to improve middle school achievement in *mathematics*, however, the current study explored *science* performance. Infusion served to contextualize the mathematics within science, while providing students with an understanding of the interconnectedness between science and mathematics.

From the literature review, an integral component of an effective infusion curriculum is the incorporation of mathematical skills that complement the science content (Frykholm & Glasson, 2005). For both mathematics and science, the impact on learning depends on the approach to integration and curriculum supports provided. The MiSP mathematics component was based on the understanding of linear relationships that 8<sup>th</sup> grade students typically find difficult and are essential for mastery of algebra. The publication of the *Common Core State*

*Standards* in mathematics also highlighted the need to integrate graph interpretations in science (National Governors Association and Chief Council of State School Officers, 2010).

Furthermore, linear relationships are part of the 8<sup>th</sup> Grade Mathematics State Standards *and* the Intermediate Level Science (ILS) State Standards (NYSED, 1996). Graphing naturally fits within the 8<sup>th</sup> grade science curriculum, particularly during the performance, analysis, and reporting of science experiments. Learning to graph has been determined to be highly contextually dependent (McKenzie & Padilla, 1986; Wu & Krajcik, 2006), which is why the current study explores how this skill can be taught in an integrated science curriculum. The graphical display of data is a tool often used by scientists to communicate ideas and trends (Sheppard, 2005).

**Integrated lesson structure for larger sample ( $N \approx 1700$ ).** In this context, 8<sup>th</sup> grade students in their middle school science class were provided with authentic data to graph and analyze after inquiry-based activities. Each MiSP lesson for any of the available topics included the following six key structural components:

- **Introduction:** An overview of the lesson and what students should learn in mathematics and science.
- **Core Curricular Area:** Major understandings, and related science standards.
- **Objectives:** Learning goals of the lesson.
- **Overview:** Suggested agendas for each day.
- **Worksheets:** Worksheets for students to complete during the lab experience that include responses for graphical representation of data, examination of slope, visual understanding of linear versus non-linear relationships. These worksheets contained the formulas necessary for completing the calculations at Stages 2 and 3 therefore no memorization was required.
- **Assessments:** Completed after the lesson.

A total of six integrated topics were presented in the infusion classes. The topics were chosen by the teachers to fit in with the particular curriculum they were teaching, i.e., General Science, Living Environment or Earth Science. Examples of topics were density, simple machines, and photosynthesis, as well as several others for a total of twenty-nine topic choices. Each topical unit included lessons that would take approximately five, 42-45 minute class periods of time to teach and contained lessons that included three different mathematical stages of graphing: Stage 1: graphical representation of data; Stage 2: Stage 1 plus the examination of slope, visual understanding of linear versus non-linear relationships; and Stage 3: Stages 1 and 2 with the addition of developing an equation of the line for use in predicting various outcomes. Having lessons available at each mathematical stage for each topic enabled teachers to utilize lessons at any time during the academic year when they normally would teach that particular science topic in their classes. New York State does not have a specified sequence for any of the sciences taught in 8<sup>th</sup> grade, therefore, there is variability in the order of topics taught in individual classes. The infusion classes were exposed to two different topics for each stage described previously. The stage of the lessons for each topic increased in complexity as the academic year progressed, for example, Stage 1 was taught in the beginning of the year (September to November), Stage 2 was incorporated into topics presented in the middle of the year (December-February), and Stage 3 was utilized in topics taught at the end of the year (March-May).

These lessons were designed to engage students in determining scales, plotting data, constructing a line of best fit, determining slope and calculating the equation of a line. The lab assignments that were part of the lessons required students to make predictions and inferences based on graphs and to utilize higher level thinking skills such as interpretation and extrapolation.



**Integrated lesson on thermal conduction for smaller sample ( $n = 136$ ).** Integration student outcomes were analyzed in more depth with a subset of the larger study population with one specific unit, thermal conduction. Many of the New York State grade 8 mathematical and science standards overlap for the sample lesson (Table 1). The shaded areas indicate performance indicators that were only taught in the infusion science classes. In addition, the lesson was correlated to the *Common Core State Standards for Mathematics*, where students must graph proportional relationships and interpret the unit rate as the slope of the graph (CCSS.Math.Content.8.EE.B.5) and they must derive the equation for a line (CCSS.Math.Content.8.EE.B.6) (National Governors Association and Chief Council of State School Officers, 2010). One additional class period was required to implement Stage 2 or Stage 3 in the infusion class. Although this may seem like a research bias, the thesis was designed to analyze whether the additional *mathematics* instruction helped students understand the *science* concepts.

Table 1

*Sample Lesson Aligned to Grade 8 Science and Mathematics New York State Intermediate Science Standards (NYSED, 1996)*

Thermal Conduction Learning Objectives			
Science Content Knowledge	Science Process Skills	Mathematics Content Knowledge	Mathematics Process Skills
Standard 4 Physical Setting	Standard 1 Analysis, Inquiry, and Design	Algebra Strand	Problem Solving Strand
Key Idea 3 (3.1a) Substances have characteristic properties. Some of these properties include heat conductivity.	Key Idea 1: Apply mathematical knowledge to solve real-world problems and problems that arise from investigations using representations such as graphs.	Describe a situation involving relationships that matches a given graph.	Observe patterns and represent problems algebraically and graphically.
Key Idea 4 (4.2a) Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.	Key Idea 2: Identify independent and dependent variables. Interpolate and extrapolate from data.	Create a graph given a description or an expression for a situation involving a linear or nonlinear relationship.	
Key Idea 4 (4.2b). Heat can be transferred through matter by the collisions of atoms and/or molecules (conduction).	Key Idea 3: Organize results, using appropriate graphs.	Interpret multiple representations using algebraic equations and graphs.	

To determine the effectiveness of this particular lesson and the implications for more intensive integration, one middle school that was part of the larger project was selected to participate in a pre-/post-lesson assessment. The sample lesson on thermal conduction is representative of the MiSP project and was the topic the study teachers were implementing in May, 2012 (the 3<sup>rd</sup> quarter of the academic year), the time of data collection. Due to the timing, the lesson assessment comprised all three mathematical stages described earlier.

**Teachers participating in the research study.** The MiSP Principal Investigator presented the program to several district administrators and recruited schools that were interested and agreeable in supporting the teachers' ability to implement the lessons, and were willing to provide student demographic data. Initially, a total of twenty-two teachers from thirteen middle schools on Long Island were chosen. Teachers were compensated for their participation in the program.

Since prior research indicated that teacher understanding of the mathematics and science content has been necessary for integration of mathematics into science (Baskkan, Alev & Karal, 2010; Kiray et al., 2008; Kiray & Kaptan, 2012), the recruited teachers were required to participate in professional workshops described below. All participating teachers held master's degrees in science teaching for grades 7-12 with certifications in Biology, Earth Science or General Science. None of the teachers who participated held certification in mathematics. The MiSP professional development was designed to enhance teacher skills such as inquiry-based methods and relevant mathematical and science content knowledge.

**MiSP professional development structure.** Three groups of teachers engaged in a two-week professional development workshop at Hofstra University in June/July 2010, 2011, and 2012. Each year was structured similarly to provide consistent preparation for teacher participants. The major difference between the years was the participating teachers. In June/July 2010 the workshop was for the first group of infusion teachers ( $n = 11$ ). In the summer of 2011, only teachers who had not previously implemented the infusion lessons (comparison teachers from 2010-2011,  $n = 11$ ) attended the workshop and in 2012 both groups attended ( $N = 30$ ). The discrepancy in the sample sizes is due to the fact that some schools and/or teachers dropped out

of the program while new recruits were added. The first day was devoted to understanding mathematics infusion strategies and building both mathematics and science content knowledge. Teachers were given the opportunity to complete a series of practice mathematics problems related to graphing, for example, finding the slope of a line and creating linear equations, in order to gauge how comfortable they were with the material. Many asked questions in areas that they did not feel confident. In addition to familiarizing themselves with the mathematics content, teachers learned pedagogical strategies for teaching the concepts to their students.

The next seven days of the workshop focused on review and implementation of the mathematics infused science lessons, with opportunities for science teachers to practice the activities. Each day teachers reviewed two lessons (2.5 hours for one lesson in the morning and 2.5 hours for another lesson in the afternoon), whereupon they would wrap-up the day and report about their lesson experiences. Finally, the last day of professional development consisted of an explanation of the research and evaluation process, logistical issues, and teacher responsibilities, as well as the collection of feedback surveys.

Utilizing the actual MiSP lessons, the teachers acted as students, which gave them an opportunity to practice each MiSP science lesson they planned to implement the following academic year. This dynamic process provided teachers with enhanced knowledge of the three graphing stages mentioned earlier, i.e. graphing, slope of a line, and linear equations, which were infused into the six science topics they would be teaching, as well as a detailed explanation of the science concepts. An additional goal of the workshop was team building to develop a strong working relationship between the MiSP staff and the science teachers.

The MiSP professional development applied the recommendations from research that has shown that in order to truly change practices, professional development should occur over

time and preferably be ongoing (Banilower, 2002; Borko, 2004). In addition, effective professional development programs require anywhere from 50 to 80 hours of instruction before teachers arrive at mastery (Supovitz & Turner, 2000; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). The total amount of professional development time teachers invested in the MiSP training was 87 hours. This number of professional development hours was achieved by teachers participating in the summer professional development for fifty hours (five hours per day for ten days), two Saturday sessions before the initial summer workshop and in between year 1 and year 2 (six hours each/twelve total hours), as well as a week-long training in June 2012 (five hours for five days/twenty-five total hours). The June 2012 session was held at the conclusion of the MiSP program; break-out groups discussed the challenges and successes of the MiSP curriculum and learned about additional resources in STEM education.

**Pre-implementation comments.** During training, teachers were given several opportunities to express their opinions. Specifically, surveys were utilized to determine how confident teachers felt about teaching an infused lesson and to see how they perceived their students would fare after the infusion lessons. The following section discusses some of their comments *prior* to delivering the MiSP lessons in their classrooms.

A sample of 22 teachers used a five-point Likert scale to indicate their level of agreement with various statements. These levels of agreement were then coded from one, strongly disagree; two, disagree; three, neutral; four, agree; and five, strongly agree. Some sample responses related to science are highlighted. Teachers somewhat agreed that after participating in the MiSP project their students would be better prepared in science than the comparison students but the responses were rated as not overly confident (Table 2). When examining the responses, only seven teachers “strongly agreed” the students would be better prepared in science as a result of being in an

infusion class, whereas fourteen of the teachers “strongly agreed” students would be better prepared in mathematics. Notably, in some of the feedback comments, teachers stated they thought they would be spending too much time explaining the mathematics involved in graphing and calculating slope and the science concepts would be lost.

Table 2

*Teachers' Confidence and Agreement After Training and Before Implementation (N = 22)*

Statement	Level of Agreement				
	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I feel confident I will be able to teach the science content in the lessons that I selected.	21	1	0	0	0
I feel confident that I will be able to teach the mathematics content in the lessons that I selected.	14	8	0	0	0
My students will enjoy participating in MOST of the lessons I selected.	7	10	5	0	0
After participating in this project, students will be better prepared in mathematics than the comparison students.	14	8	0	0	0
After participating in this project, students will be better prepared in science than the comparison students.	7	12	2	1	0

In one of the earlier meetings in March 2010, teachers were asked to assess their own mathematical confidence and a contradiction was discovered. Although twenty teachers reported they did not need further assistance, only eight teachers found the lessons very easy or somewhat easy to teach (Table 3). This suggested that although teachers recognized their mathematical limitations they were unable to identify specific areas in which they would need additional support.

Table 3

*Teachers' Perceived Ease of Teaching Lesson, Pre-Implementation (N = 22)*

Statement	Very hard (1)	Somewhat hard (2)	Neither easy nor hard (3)	Somewhat easy (4)	Very easy (5)
How easy will it be to teach this lesson?	2	7	5	7	1

**Teachers' preliminary concerns.** Answering the prompt of “What concerns do you have of implementing an infused lesson,” participating teachers made several comments. Two teachers cited the need for supplies and resources, e.g. photocopied lab reports and materials needed for the lab activity. Three teachers expressed concern that the mathematics focus would impede the development of student understanding of scientific concepts and four teachers felt the mathematical skills of the students would be too low to understand the mathematics-science relationship. The biggest concern, however, was time. Thirteen of the nineteen teachers specified time as the number one obstacle to integration (Figure 3). They believed that juggling student needs and the think time needed for the mathematics component of the lesson would take time away from the amount available to cover the scope of the science curriculum. These concerns and other challenges to implementation were addressed at follow up meetings.

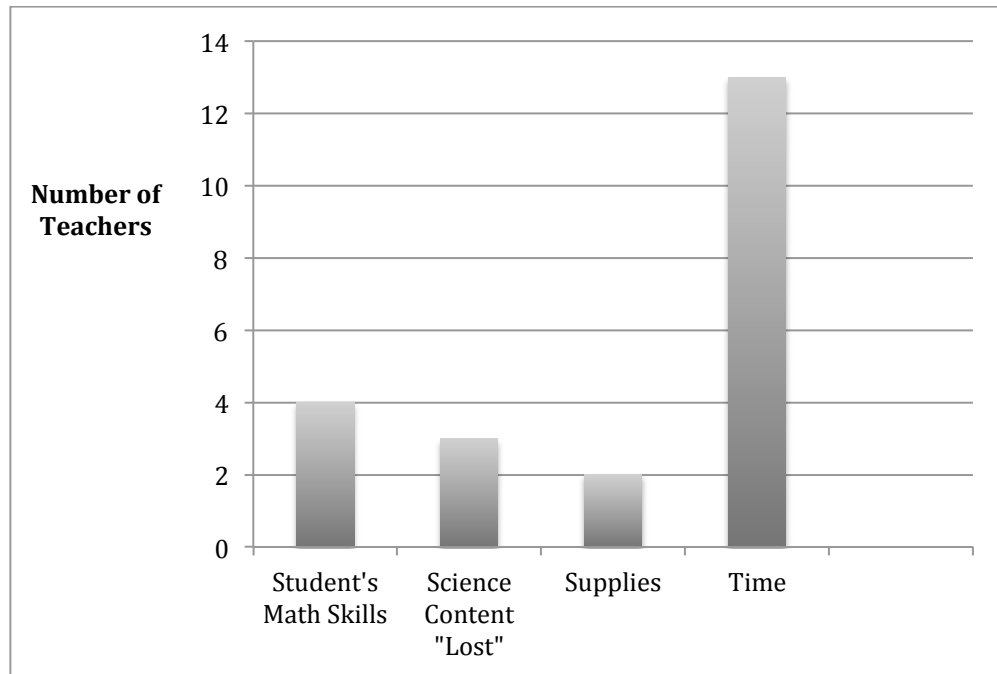


Figure 3. Teachers' preliminary concerns related to implementing infused lessons ( $N = 22$ ).

### 3.4 Setting and Study Population

The research in the current study involved two data sets. One set included student assessments and attitudes from eighth grade students and their teachers from several school districts on Long Island, New York and consisted of 28 teachers and approximately 1700 students in both infusion and comparison classes. Demographics of this group are displayed below (Table 4). In the ethnicity subgroup, in consideration of traditional underrepresentation of Black and Hispanic students, groupings were designated as White and Non-White, with White being 74.4% and Non-White as 25.6%. Although all school districts agreed to participate in the study, due to teacher reporting of subgroups, some student demographic data was missing. Some schools failed to report any student demographics in certain sub groups leaving as many as 40% or approximately 1300 out of 3200 students without a particular designation. Revised sample sizes for these subgroups are indicated in Table 4.



Table 4

*Student Demographics for Integrated Content Analysis*

Student Characteristic	Comparison	Infusion
<u>Gender (N = 1673)</u>		
Male (n = 882)	215	667
Female (n = 791)	233	558
<u>Ethnicity (N = 1691)</u>		
Underrepresented minority (n = 435)	117	318
White (n = 1256)	330	926
<u>Free/Reduced Lunch (N=1607)</u>		
Low SES (n = 314)	106	208
High SES (n = 1293)	342	951
<u>Special Education (N = 1635)</u>		
No IEP (n = 1531)	415	1116
IEP (n = 104)	33	71
<u>Limited English Proficiency (N = 1692)</u>		
Non ELL (n = 1629)	434	1195
ELL (n = 63)	14	49

ELL: English language learners

IEP: Students with individualized educational plans

In the second data set, a lesson assessment on thermal conduction was analyzed from one particular school on Long Island, New York. There were 136 students (infusion and comparison) involved at this location. The lesson analysis provided an interesting context for exploring the research questions on the success of an integrated curriculum, and how schools might use this data in curriculum planning. The district chosen for the lesson assessment analysis serves a population of approximately 11,000 students with a student demographic which is 92% White. The town that the school district is located in has over 40% households with school age children and the median income is twice the national average (\$81,000 vs. \$40,000). All classes in the study setting were General Science classes; no accelerated classes (Regents Earth Science) were involved in the study. Table 5 summarizes the demographic distribution for the lesson

assessment administered to comparison and infusion students at this setting. Again due to teacher reporting of data, only gender was reported in each of the groups.

Table 5

*Student Demographics for Lesson Assessment Analysis (n = 136)*

Student Gender	Comparison percentage (number of students)	Infusion percentage (number of students)
Male	55% (17)	48% (50)
Female	45% (14)	52% (55)

All of the science teachers involved in this study have similar teaching experience. They worked with Hofstra University and participated in training for implementing an integrative lesson expanding teacher competence in this practice. Table 6 highlights the professional experience of the three teachers involved in the thermal conduction lesson at the time of the data collection in 2012.

Table 6

*Professional Credentials of Teachers Implementing Thermal Conduction Unit*

	Teacher #1 Infusion	Teacher #2 Infusion	Teacher #3 Comparison
NYS Certification	Biology General Science 7-12	Biology General Science 7-12	Biology General Science 7-12
Years Experience	11	11	18
Certification Year	2001	2001	1984

### 3.5 Data Collection Instruments

**Student content knowledge.** The pre- and post-integrated content knowledge assessment (see Appendix A) was administered to infusion and comparison students at the start and end of the academic year to assess their understanding of the three stages of graphing as described previously. The students were advised that the instrument would not be used as a factor for determining their grade point average and that the results were strictly for experimental purposes, thus consequential validity was addressed. The assessment tool was developed and reviewed for content validity by an evaluation team of relevant experts. The evaluation team consisted of master teachers with more than ten years of experience in teaching science and/or mathematics from middle and high school settings as well as college level professors. Also on the team were reputable researchers in the field of mathematics assessment and educational philosophy. To make the study more meaningful to the premise of science achievement, only those questions that were determined to be similar to questions from the 8<sup>th</sup> grade standardized exam were used to analyze student proficiency. This question selection was again done by a group of experts similar to the evaluation team described previously.

The integrated content knowledge assessment (Appendix A) was pilot tested at a middle school on Long Island that was not in the study, but had similar demographics. The assessment was administered to 280 eighth grade students (male = 156, female = 124) in 2009-2010. Two different protocols were used to evaluate the assessment. The first protocol involved a “read-aloud” with a researcher. The student read aloud the assessment questions and talked about anything that seemed to be unclear or confusing while the researcher took notes. In this way, substantive validity was addressed. The second type of protocol was a timed administration to see if students had enough time to finish within one class period of 40-42 minutes. Revisions

were made in response to student data that indicated fewer items were necessary for students to complete the assessment in the allotted timeframe. The final assessment items consisted of 14 total questions, 10 of which were used for this study. These 10 questions involved ideas where mathematics was specifically applied to a science context, and students could have earned a maximum of 11 points (see point allocation in Appendix A). These questions required both multiple choice and short answer responses, with students needing to complete several steps to demonstrate proficiency. Two experienced teachers scored the assessments using a scoring rubric. Twenty-five assessments were graded by both raters, allowing for examination of interrater reliability using Cohen's kappa ( $\kappa = .87$ ). Ratings of these 25 assessments were significantly correlated ( $r = .86$ ), indicating substantial agreement in scoring between the two individuals (Landis & Koch, 1977).

**New York State standardized exams.** To provide evidence of convergent validity for the integrated content knowledge assessment, Pearson correlations were measured with scores from standardized science and mathematics exams. Currently, New York State requires students in 8<sup>th</sup> grade to take a mathematics assessment, and if students are not in an advanced science course, an Intermediate Level Science (ILS) exam. The Grade 8 ILS is designed to measure the content and skills contained in the Intermediate Science Core Curriculum, Grades 5–8 (NYSED, 1996). The core curriculum is based on the New York State Learning Standards for Mathematics, Science, and Technology. The New York State Grade 8 ILS test consists of two required components: the Written Test and the Performance Test. The Written Test consists of multiple-choice and open-ended questions. The Performance Test consists of hands-on tasks set up at three different stations. Many of the assessment items have calculation and graphing requirements. These requirements highlight the emphasis given to algebra in general and

graphing in particular. As stated in the National Mathematics Advisory Panel Final Report (2008), algebra is a gateway subject for success in higher education and career success because it builds a foundation of abstract reasoning. The Panel goes on to say that students are more likely to graduate from college if they have completed Algebra courses compared to students who have not. Analysis indicated that students' scores on the ILS exam were positively correlated with their performance on the Student Content Knowledge Assessment ( $r = 0.43, n = 1056, p < .001$ ), a moderate to strong correlation given the large sample size (Field, 2013; Rosenthal & DiMatteo, 2001).

Scores from the New York State 8<sup>th</sup> grade Mathematics Exam were also collected. The Mathematics Exam contained a combination of multiple-choice and open-ended questions that were scored to produce individual student raw scores. Student scores were then translated and categorized into four achievement levels: Level 1 (indicating no proficiency), Level 2 (indicating basic proficiency), Level 3 (indicating proficiency), and Level 4 (indicating advanced proficiency). A school's performance index is a function of the percentage of its students falling into each of these performance levels. Schools may use these performance indices to determine whether students need additional educational support services or as a consideration for class placement in future science and mathematics courses. Analysis indicated that students' scores on the 8<sup>th</sup> grade Mathematics Exam were positively correlated with their performance on the Student Integrated Content Knowledge Assessment ( $r = 0.45, n = 1564, p < .01$ ). Students' scores on the ILS and Mathematics Exams were also positively correlated with each other ( $r = 0.65, n = 1056, p < .01$ ).

**Lesson assessments for smaller sample.** In order to evaluate integrated science ability further, a subgroup of students in an infusion and comparison class ( $n = 136$ ) at one middle

school on Long Island completed an assessment at the conclusion of the five-period lesson plan for the chosen science topic in thermal conduction (Appendix B). As with the integrated content knowledge assessment, the selection of the questions for the topic lesson assessments was an iterative and highly collaborative process that involved the project team leaders, experts in the area of mathematics and educational psychology, and experienced mathematics and science teachers, many of whom were involved in previous Mathematics, Science and Technology (MST) programs. Two professors who have curriculum writing experience and are familiar with middle school science and mathematics wrote the unit assessments. They followed the parameters set forth in the New York State Intermediate Science Core Curriculum (NYSED, 1996). The MiSP Team reviewed the assessment to make sure that it fit the MiSP model. The assessments were also reviewed by middle school mathematics and science teachers to assess the relevance of the mathematics to the science, and the importance of the science content being taught. The goal was to assure the content validity of both science and mathematics of the lesson assessment.

The lesson assessment consisted of multiple choice, short answer and open-ended questions that could be completed by students within the time constraints of a class period of approximately 40 minutes. Research has suggested that open-ended assessments may probe student understanding in greater depth when measuring the effectiveness of integrated curricula (Merrill, 2001). The assessment included questions about the science concepts that were explored during the infused lesson as well as application questions requiring mathematical skills in graphing. This study analyzed results from the assessment on the thermal conduction lesson. A total of 13 questions were evaluated on the lesson assessment with only none or full credit given to each response. This lesson assessment was given to *both* the comparison and infused classes

*before* and *after* the weeklong lesson instruction. This particular topic was taught using Stage 3 mathematical skills and chosen by the teachers in the study to fit with their 8<sup>th</sup> grade General Science curriculum at the time of data collection. Two experienced teachers scored the assessments using a scoring rubric with an interrater reliability of  $\kappa = .74$ .

**Student attitude survey.** A survey measuring student attitudes (see Appendix C) was administered to both infusion and comparison students. Students were told the survey was to be used in an educational research study to minimize survey bias. Students were asked how important they expected mathematics to be in their science class and their opinion of themselves as science students. Several other Likert-type questions about mathematics and science were presented and were classified into two factors: *confidence* (in science ability) and *agreement* (with the importance of mathematics in learning science) - see Table 8 (p. 70) for information on factor analysis and identification of constructs. For the confidence questions students used a ten point rating scale with response options on a continuum from (0) not at all confident to (10) highly confident. For the agreement questions students used a five point rating scale with response options (1) strongly disagree to (5) strongly agree. No other written descriptives were labeled on the scale.

*Reliabilities.* The items associated with the factors, confidence and agreement, comprised the scales of the survey. The reliabilities (internal consistencies) of the scales, assessed by Cronbach's alpha values, were: confidence (0.91), and agreement (0.87). Nunnally and Bernstein (1994) and Field (2013) noted that measures with  $\alpha$  of 0.70 or above are considered reliable.

**Online teacher survey.** At the end of the academic year, the infusion teachers gave feedback regarding lesson implementation and student reactions in an online survey (Appendix

D). The survey included 18 questions that asked teachers to identify the topic and stage of mathematics incorporated in the lessons. It then asked teachers to consider successes and challenges to the lesson in terms of implementation and student understanding. There was also the opportunity for teachers to describe any variations they made in the lesson administration to better fit their classroom needs.

**Timeline of research activities.** The following timeline (Figure 4) illustrates the sequence of administration of the data collection instruments. The thermal conduction lesson assessment was administered to the subset sample ( $n = 136$ ).

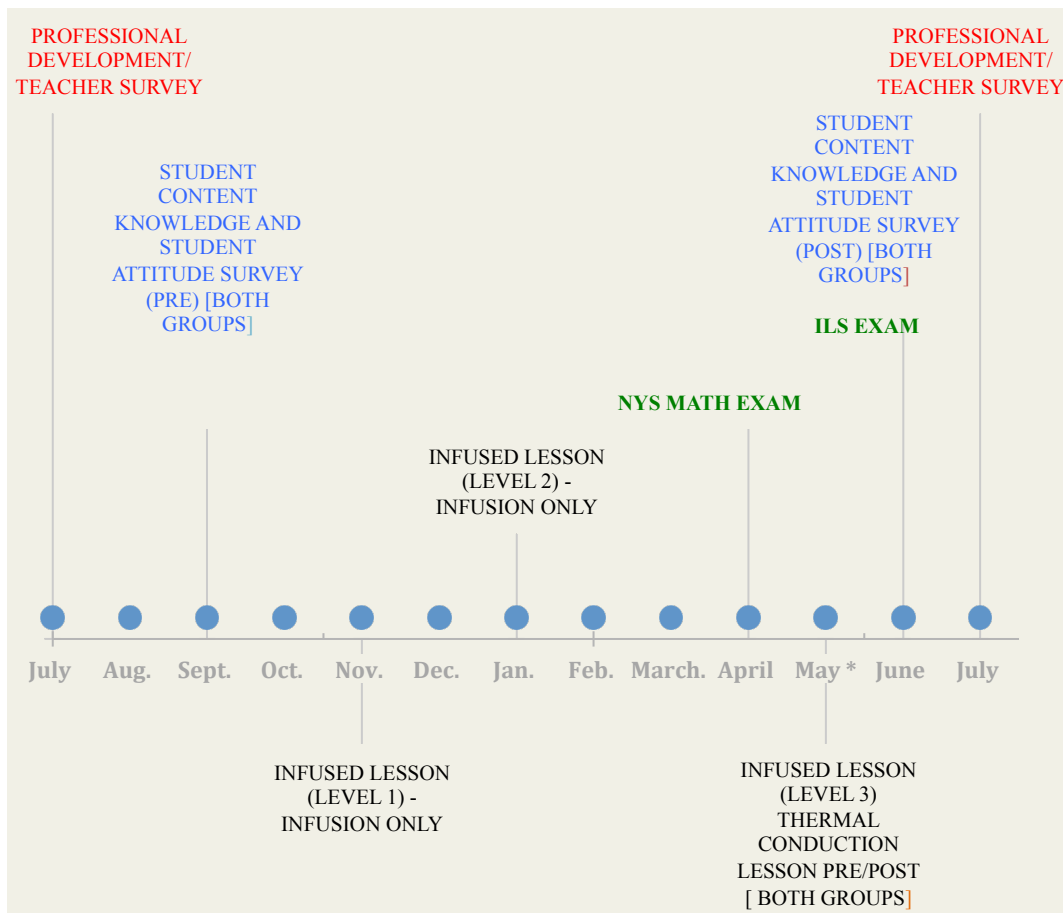


Figure 4. Timeline of instrument implementation.



**Instrument quality.** In order to make inferences based on the findings of these assessment tools, it is important to evaluate the quality of the instruments. To that end, evidence of validity and reliability for the assessment tools is discussed. Reliability, according to the *Standards for Educational and Psychological Testing* (American Educational Research Association, 2004) measures the ability of an instrument to provide consistent results. The components of reliability that have been examined are internal consistency and inter-scorer reliability. A measure of internal consistency was determined using Cronbach's alpha reliability coefficient (Cronbach, 1951). The Cronbach alpha coefficient is an index of scale internal consistency of the test items relative to other test items, which are designed to measure the same construct of interest. The Cronbach coefficients are listed in Table 7 and suggest all assessment tools were reliable for use. Values greater than 0.70 are supportive of reliability inferences (Cronbach, 1951).

In addition to reliability the study also investigated validity standards. Validity refers to the degree to which theory and evidence support the interpretations of test scores and whether the questions cover the construct being tested, under specific circumstances. Messick (1995) unified these standards into six aspects of construct validity, which he stated could function as general validity criteria for all educational measurements. These six aspects of validity are content, substantive, structural, generalizability, external and consequential. In order for the MiSP integrated content exam to be used to inform instruction, its scores must be valid. Content validity, one of the most important aspects of instrument quality, was based on theoretical grounding of experts in science education and a review of middle school science and mathematics literature.

The results of several tests indicate that the instruments used in this study had several parameters of reliability and validity associated with them as summarized in Table 7.

Table 7

*Evidence of Instrument Reliability and Validity*

Instrument	Reliability	Validity
Student Integrated Science Content Assessment	Interrater reliability, $\kappa = .87$ Internal consistency, $\alpha = .77$	Content validity: by teacher experts Substantive validity: read alouds, student input Consequential validity: tests not used for students' GPA External and convergent validity: compared with ILS exam ( $r = .43, n = 1056, p < .01$ ) External and convergent validity: compared with mathematics exam ( $r = .45, n = 1564, p < .01$ )
Thermal Conduction Lesson Assessment	Interrater reliability, $\kappa = .74$ Internal consistency, $\alpha = .79$	Content validity by experts and review of ILS standardized tests
Student Attitude Survey	Internal consistency for subsections: Confidence, $\alpha = .91$ Agreement, $\alpha = .87$	Content validity by expert panel modified from Math Science Technology Project (MSTP) Substantive validity: field tested at similar demographic setting
Teacher Attitude Survey	Internal consistency for confidence $\alpha = .91$	Modified from National Survey of Science and Mathematics Education (Horizon Research, 2000)

Rasch Analysis was used as an item response theory (IRT) approach. Advantages of Rasch analysis have been discussed by many researchers (Boone & Scantlebury, 2006; Neumann,

Neumann, & Nehm, 2010). One benefit of Rasch modeling is the ability to analyze the quality of items within an instrument by calculating fit indices. These indices can highlight discrimination between the items and the test takers as well as identifying repetitive items. The more items that fit, the better the instrument for measuring outcomes. Rasch analysis was conducted using WINSTEPS software (Linacre, 2006). The Rasch test indicated the quality of the items on the integrated content exam was acceptable (item fit = 1.00; person fit = 1.00), in that students who got difficult questions correct also got easier questions correct. These values are considered reasonable for both high stakes and low stakes assessments (Wright & Linacre, 1994).

A principal component factor analysis was performed on the student attitude survey in order to determine the major constructs within student attitudes that were of interest to the study. This analysis yielded loading that converged on two scales, confidence and agreement, with high correlations between items and factors (Table 8). Students indicated their level of agreement with the statements summarized as item descriptions.

Table 8

*Factor Loadings Based on a Principal Component Analysis with Varimax Rotation*

Item Description	Confidence	Agreement
Correctly constructing a graph	0.74	
Correctly labeling axes and title	0.72	
Selecting appropriate scale	0.72	
Identifying independent and dependent variables	0.73	
Answering questions about a graph	0.72	
Math is important for completing tasks in science.		0.73
Being able to do math makes science easier.		0.73

**Summary of prior findings related to mathematics achievement.** The following section will detail MiSP project findings as related to mathematics achievement. Although the purpose of this study relates to *science* achievement, the purpose of the original MiSP Project

was to determine if students performed better in *mathematics* as a result of being in an infused classroom. The two indicators used to determine improvement were the New York State 8<sup>th</sup> Grade Mathematics Exam and pre-/post-integrated content exam.

The recently published year-end analysis of the MiSP data found that overall, a significant number of infused students demonstrated improved achievement on both the project assessment and the 8<sup>th</sup> Grade Mathematics Exam as compared to those students not in the program (Burghardt, Lauckhardt, Kennedy, Hecht, & McHugh, 2015). Additional major findings can be summarized as follows:

- Infusion students showed significant mathematics gains from the MiSP pre-/post-test greater than the increases typically expected over the school year (Table 9).
- Infusion students performed significantly better than comparison students on the mathematics post-test after controlling for pre-test score differences (Table 9).
- Infusion students performed significantly better on the 8<sup>th</sup> grade mathematics state assessment than comparison students.

Table 9

*Students' Percentage Correct on Mathematics Content Knowledge Assessment*

Group	<i>N</i>	Pre-MiSP	Post-MiSP	Mean difference
Infusion	641	40.7%	54.8%*	14.1%
Comparison	559	44.0%	49.5%*	5.5%

\* $p < .01$

The present study built upon Burghardt et al.'s work in several ways. It extended beyond mathematics to examine the impacts of the MiSP program on students' science achievement and attitudes towards integration. Student outcomes were analyzed by specific demographic subgroups, including gender, ethnicity, socioeconomic status, and English language proficiency.

Evidence of gains in understanding was compared with teacher attitudes towards integration, which provided data of whether teacher confidence in implementing the integrated model was related to student performance on validated assessments.

### **3.6 Research Design and Methods**

The purpose of this research was to evaluate student-level outcomes of an integrated curriculum in terms of assessment results and student and teacher perceptions. A quasi-experimental quantitative design was employed to measure outcomes for 8<sup>th</sup> grade students. Treatment and control student groups were chosen from middle schools throughout urban and suburban regions in New York State; the group assignments depended upon their teachers participating in the MiSP Program and were not completely random. Formed groups in intact classrooms either received the treatment (infusion) or not (comparison), and both took pre- and post-assessments. For the teachers, a pre-experimental quantitative design was utilized. These teachers participated in the MiSP professional development training but data were not collected from a control group for teacher-specific variables. Teacher data and student data were compared to assess their consistency.

**Quantitative data sources and collection procedures.** Quantitative results provided the empirical data to analyze infusion as it pertained to student achievement on assessments. The assessments include the integrated content assessment given at the beginning of the year and the end of the year to the entire data set as well as an assessment given before and after the unit on thermal conduction at the one Long Island middle school setting. The quantitative analysis in this study incorporated several techniques to explore whether infusing mathematics into science affects integrated science achievement.

To document integrated mathematics and science content knowledge and answer Research Question 1, students in both the infusion and comparison groups took an integrated content assessment in September and then again in June. The data were controlled for pre-test scores as well as the New York State Grade 7 Mathematics Exam scores, and comparisons were made among infusion subgroups defined by gender, ethnicity, special education status, English proficiency, and poverty levels in terms of free or reduced lunch eligibility (for criteria, see United States Department of Agriculture, Food and Nutrition Service, 2013).

To document integrated mathematics and science content knowledge that was *specifically linked to the lesson taught* (thermal conduction) and to answer Research Question 1, students at the selected school completed a lesson assessment tool that is a part of the MiSP project. Again, both the infusion and comparison students who attended the selected school were administered the lesson assessment prior to the lesson and then again immediately following for a post evaluation. The time duration between pre- and post-evaluation was no more than five days. Comparisons were made between treatment and comparison groups, and male and female students were compared within the infusion group.

Utilizing these two assessments, an analysis of covariance (ANCOVA) was performed to assess the progression of student knowledge over time and compare those students exposed to infusion and those in the comparison. The dependent variable was post-test score with pre-test score and grade 7 math score as covariates, and independent variables for the content exam included group, gender, socioeconomic status, ethnicity, special education status, and English language proficiency. For the lesson assessment, the dependent variable was post-test score with pre-test score as a covariate, and the independent variables included group and gender. Effect sizes were calculated for both ANCOVA analyses.

To document student attitudes, comparisons between student responses at the start of the year to the end of the year were used to answer Research Question 2. A student attitude survey was administered to students in the fall and spring and was found to be understandable in both format and content. The survey was divided into two subtopics - confidence and agreement. ANCOVA was used to analyze the student responses and an effect size was calculated. The dependent variables were confidence and agreement post-survey composites with pre-survey composite as a covariate; the independent variable was group. In addition, Pearson correlations were made between the student attitudes and the integrated science content assessment, and effect sizes were measured; these data were used to answer Research Question 3.

To answer Research Question 4, results from the teacher attitude survey ( $N = 28$ ) were compared with results from student science performance and student attitudes assessments. Pearson correlations and effect sizes were measured.

### **3.7 Hypotheses**

After reviewing student achievement in *mathematics* as a result of the MiSP project, it was hypothesized that students would also achieve success in an integrated *science* content as determined by their assessment scores as a result of the treatment. Table 10 summarizes the corresponding null hypotheses, variables and statistical tests associated with each research question.

Table 10

*Null Hypotheses as Related to the Research Questions*

Hypotheses	Dependent Variables	Independent Variables	Statistical Tests
Q1.A: Students enrolled in an infusion science class do not show significantly higher learning gains from pre- to post-on the student content assessment ( $N \approx 1700$ ) than those in the comparison class ( $p < .05$ ).	Integrated Science Content Assessment scores	Mathematics/ Science infusion instruction Student demographics	1. ANCOVA 2. Linear Regression Methods 3. Effect size
Q1.B: The scores of students enrolled in an infused science class do not show significantly higher learning gains from pre- to post-on the lesson assessment ( $n = 136$ ) than those in the comparison class ( $p < .05$ ).	Thermal Conduction Assessment scores	Mathematics/ science infusion instruction Student demographics	1. ANCOVA 2. Effect size
Q2.A, Q4: Students in an infusion science class do not have significantly higher gains in their science confidence and agreement with the importance of mathematics in science as compared to the comparison group ( $N \approx 1700$ ).	Student Attitude Survey with following domains: confidence, self-efficacy, interest and utility of mathematics	Mathematics/ Science infusion instruction Student demographics	1. ANCOVA 2. Effect size 3. Exploratory factor analysis for Likert responses
Q3: Positive student attitudes do not correlate with student learning gains on the content assessment ( $N \approx 1700$ ).	Content proficiency and students attitudes	Mathematics/ Science infusion instruction Student demographics	1. Pearson Correlation 2. Exploratory factor analysis for Likert responses
Q4.A: Teachers of the infusion model do not have more confidence and positive attitudes toward an integrative curriculum and resulting student achievement ( $N = 28$ ).	Teacher Attitude Survey with attitude and confidence domains	Teacher characteristics	1. Pearson Correlation
Q4.B: Teachers' attitudes and confidence do not positively correlate with student learning gains on the content assessment.	Student learning outcomes and attitudes	Teacher characteristics	1. ANCOVA 2. Pearson correlation



### 3.8 Limitations

The researcher, a middle school science teacher, was a participant in the MiSP professional development program. She attended the summer training sessions and implemented the mathematics-science integrated curriculum in her classroom. In terms of actual quantitative data, the researcher's students were part of the overall study but the data were completely de-identified when accessed for analysis. However, she acknowledged her investment of time and effort in the professional development. As such, self-reflection of the researcher enhanced the analysis but also potentially influenced the interpretation of the statistical findings.

In addition, the study location can also be seen as a limitation to generalization assumptions. Long Island, as a region, is unique in its student demographics. Using data from the New York State School Report Cards (NYSED, 2012), a ranking of Long Island school districts was created where the higher the number the better the school district. The specific data analyzed were graduation rate, college plans, Regents Diploma with Advanced Designation and Regents scores in English, Algebra and Global History and Geography. The average school district on Long Island had a composite score of 73.8. The New York State average was 58.7. The study settings had an average score of 81.2. Only 14% of all Long Island students attend a high needs school district. There are, however, extremely large racial and ethnic differences: 76% of all students in high-need districts are Black and Hispanic (Long Island Index, 2009). In particular, the middle school where the Thermal Conduction Lesson Assessment was administered had an overwhelming majority (92%) of White students. According to the School Report Card, the percentage of free and reduced lunch combined was 4% and only 1% of students were English Language Learners (NYSED, 2012). Although not diverse, this school district is representative of many school districts on Long Island (Long Island Index, 2009). Other districts involved in

the study do have minority, ELL and high poverty students represented with varying levels within the data set. When analyzing the content assessment and student attitudes, care was taken in disaggregating subgroup results.

Another limitation had to do with the nature of surveys in general. The analysis of attitudes was based on student and teacher self-reports. Without direct observation or interview data it is difficult to determine the accuracy of these assessments.

Other limitations were the many variables that may contribute to, or hinder, academic success or failure. These variables included teacher competence and expectations as well as the fidelity of lesson implementation. Although teachers in the infusion classes were provided with MiSP lesson plans, and professional development, the delivery of the content varied among teachers. Some researchers have suggested that the expertise of the educator is the key factor in determining whether integration will produce positive outcomes in students (Chauvot & Lee, 2015; Clayton, 1989). One limiting factor related to teacher effectiveness is content knowledge (Borko & Putnam, 1996). Some of the science teachers had a higher level of mathematics competency and others had access to and utilized their mathematics colleagues.

Apart from content knowledge, the ability and confidence to teach across disciplines is critical to deliver integrated lessons. In order for students to make the mathematics-science connections, the integration must be explicit (National Research Council, 2014). Teachers need to know how to provide instructional support that help students recognize the connections between the disciplines. Students' prior knowledge in the individual disciplines is also a factor. Limited mathematical skills or having relatively no understanding of foundational ideas in each discipline makes it challenging for those students to make relevant connections.

### **3.9 Contribution to Teaching and Learning of Science**

The goal of this research study was to provide empirical evidence to evaluate the philosophical view that mathematics and science should be taught in an integrated fashion at the middle school level. The dependent variables measured the extent to which students utilized mathematical skills of graphing and science knowledge in problem solving activities and their attitudes regarding integration; this was represented by scores on integrated content assessments and responses to the attitude survey.

The findings from this research may be of interest to curriculum developers and to educators looking to address mathematics integration in their middle school science classroom, those who design curricula, and those who train pre-service and in-service teachers of mathematics and science. Innovative approaches to science that incorporate multiple disciplines have shown promise for increasing the scientific literacy and proficiency of young students (Cajas, 2001), and this study provided evidence for the effectiveness of such strategies.

It is essential that students develop proficiency in mathematical skills in order to master many scientific concepts (Wilkins, 2000). Concurrently, an integrated curriculum should foster an increase in the ability to make decisions, think critically and creatively, and synthesize knowledge beyond the disciplines. This study supported the seamless integration of mathematics and science to improve learning for all middle school students. Students may recognize the value of mathematics in doing science and vice versa. In doing so, students may be more likely to persist in the study of STEM-related disciplines since they will see the relevance and importance of cross-curricular concepts (National Research Council, 2011).

### **3.10 Conclusion**

According to the National Academy of Sciences paper on STEM integration (2014), in order to successfully evaluate an integrative curriculum the assessment tools must directly measure the connected concepts and skills taught in the infusion class. Both the pre-/post-content exam and the pre-/post-lesson assessment were reflective of the specific intervention experience. Literature in STEM curricula has advocated that mathematics and science be taught in an integrated fashion in order for students to utilize skills from both disciplines in problem solving activities. Consequently, the core hypothesis that guided this study was that an integrated science curriculum should enable students to improve their performance on integrated content assessments and have positive associations with an integrated curriculum. Several other findings were anticipated, including students' increased ability to understand mathematics and science concepts in an integrated class and positive associations with an integrative curriculum by both students and teachers. The data provided empirical evidence for evaluating the potential for integration, which will inform future efforts to replicate the proposed reform model.

## Chapter 4

### Results

#### 4.1 Introduction

The purpose of this research was to investigate the performance and attitudinal impacts of infusing mathematics into an 8<sup>th</sup> grade science curriculum. Descriptive statistics for the student integrated science content knowledge, pre- and post-assessment scores on an integrated lesson assessment, and student and teacher attitudinal surveys were analyzed using repeated measures ANCOVA and correlational analysis. Based on the statistical tests utilized, this investigator established significant results for several parameters. This chapter, organized by research questions, provides a discussion of the results. The research questions include the following:

- Research Question 1: Have students' understandings of integrated science content improved as a result of the infused curriculum?
- Research Question 2: Have students' attitudes towards the relationship between mathematics and science changed as a result of participating in the infused curriculum?
- Research Question 3: How do students' views on integration correlate with their performance on an integrated science assessment?
- Research Question 4: How does teacher confidence relate to science learning outcomes and student attitudes?

Descriptive statistics for the student integrated content knowledge pre-/post-assessments, along with an analysis of the treatment on separate demographic groups, is presented followed by results of the thermal conduction lesson assessment including gender impact (Section 4.2). An analysis on student attitudes towards mathematics-science integration is discussed (Section 4.3),

and how student attitudes correlate with student achievement (Section 4.4). Correlational analysis of teacher attitudes and student achievement and attitudes (Section 4.5) is reviewed and individual teacher impact is examined. The results are summarized in Section 4.6.

#### **4.2 Research Question 1: Have Students' Understandings of Integrated Science Content Improved as a Result of the Infused Curriculum?**

**Student integrated science content knowledge assessment.** Before analyzing the integrated science content knowledge assessment (Appendix A), raw performance scores were recorded to facilitate statistical analyses. The integrated content exam consisted of 5 multiple choice and 5 short response questions. Raw scores on the integrated content exam were based on total scores with either full or no credit given to each multiple choice question (0 or 1) and full or no credit was given to each short response question (0 or 1), with the exception of question 10, which allowed for partial credit and was scored as such: 0 for no credit; 1 for partial credit; 2 for full credit. Thus, the total number of points a student could earn on the integrated content exam was 11.

Post-integrated content scores were used as measures to determine if students in the infusion class were more successful in terms of achievement than students in the comparison class. An analysis of covariance (ANCOVA) was used to explore post-test variation between the different groups (infusion and comparison) and post-test variation among several demographic subgroups within the infusion sample. ANCOVA allows for the use of covariates which are variables that may bias the results of the post-exam; in addition, the use of covariates in evaluating treatment effectiveness has been shown to increase statistical power substantially by reducing within-cluster variance (Hedges & Hedberg, 2007). This study uses pre-test scores on the Integrated Science Content Exam as well as the New York State Grade 7 Mathematics Exam

as covariates. Since this was an integrated mathematics-science curriculum, the Grade 7 Mathematics Exam was chosen as a covariate to minimize any impact of mathematics ability on the post-test score. Preliminary analyses were performed to ensure the assumptions of the ANCOVA were satisfied and the test could be used with confidence. A Levene's test of equality of variances, or homoscedasticity, was performed and revealed that there were equal variances between groups and the assumptions for homogeneity of slopes were met.

Relationships between the covariates and the dependent variable (post-test) did not differ significantly as a function of the independent variables (group and specific demographic subgroups) for the Integrated Science Content Exam. Scatter plots were generated and showed the dependent variable (post-test) was linearly correlated with the covariate (pre-test), and there was no linear correlation with the independent variable (group) and covariate. Pearson correlations confirmed these results. Since the data set was large ( $n > 300$ ), normality was determined by a histogram, which showed the absolute value of skewness and kurtosis to be very close to 0. In addition, a normal P-P plot showed there were no outliers.

***Science content knowledge analysis by group.*** The analysis of treatment effect indicated that scores on the post-content assessment were significantly higher for students in the infusion group compared to those in the comparison group ( $F(2, 447) = 17.02, p < .001$ , Cohen's  $d = .20$ ). Students in the infusion class ( $M = 6.87, SD = 1.72$ ) had significantly higher mean scores than students in the comparison group ( $M = 6.49, SD = 1.71$ ) with a small effect size.

***Science content knowledge analysis by gender.*** Gender, defined as male or female, was statistically significant in the overall group with a small effect size ( $F(2, 790) = 22.49, p < .001, d = .23$ ), with females ( $M = 7.01, SD = 1.80$ ) outperforming males in integrated science content

scores ( $M = 6.63$ ,  $SD = 1.84$ ). In the comparison group, descriptive statistics for female students were  $M = 6.93$ ,  $SD = 1.76$ , and for male students were  $M = 6.33$ ,  $SD = 1.97$ . Although infusion and gender were both found to be statistically significant independent variables, there was no interaction effect. Females outperformed males in both treatment and comparison groups but the treatment was equally effective for both males and females.

***Science content knowledge analysis by socioeconomic status.*** This study characterized students as low socioeconomic status (SES) if they were eligible for free or reduced lunch and as high SES if they were not eligible. At the time of this study, free lunch was available to students whose families earned less than 130% of the poverty level, or \$30,615 for a family of four; reduced lunch was available to students whose families earned between \$30,615 and \$43,568, or 185% of the poverty level (United States Department of Agriculture, 2013). SES was not found to be a significant predictor variable for performance in the overall group. No significant differences were observed for low SES and high SES students ( $F(2, 313) = .971$ ,  $p = .325$ ). There was no interaction effect between poverty and group. Mean scores by subgroup included: high SES, infusion ( $M = 6.84$ ,  $SD = 1.86$ ); low SES, infusion ( $M = 6.76$ ,  $SD = 1.85$ ); high SES, comparison ( $M = 6.64$ ,  $SD = 1.85$ ); and low SES, comparison ( $M = 6.66$ ,  $SD = 2.00$ ).

***Science content knowledge analysis by ethnicity.*** Additional analyses were performed by exploring student differences when considering ethnicity. This study distinguished ethnicity by coding students into 2 groups: White or non-White (American Indian, Black and Hispanic). Even though White infusion students scored higher than non-White students on the Science Integrated Content Assessment, these differences were not statistically significant ( $F(2, 434) = .038$ ,  $p = .845$ ). Mean scores by subgroup included: White, infusion ( $M = 6.72$ ,  $SD = 1.68$ ), non-White,



infusion ( $M = 6.32, SD = 1.69$ ); White, comparison ( $M = 6.49, SD = 1.71$ ); and non-White comparison ( $M = 5.91, SD = 1.72$ ). There was no interaction effect between ethnicity and group.

***Science content knowledge analysis by English language proficiency.*** Students classified as English language learners (ELL) were considered to have limited English proficiency (LEP) because either they understood and spoke little or no English, or they scored below a New York State designated level of proficiency on the English Language Assessment (ELA). No statistical significant differences in performance on the Science Integrated Content Assessment were observed between LEP and non-LEP students in the overall group ( $F(2, 62) = .031, p = .861$ ). Mean scores by subgroup included: LEP, infusion ( $M = 5.78, SD = 1.85$ ); non-LEP, infusion ( $M = 6.90, SD = 1.86$ ); LEP, comparison ( $M = 6.29, SD = 1.82$ ); and non-LEP, comparison ( $M = 6.65, SD = 1.89$ ). There was no interaction effect between English language proficiency and group.

***Science content knowledge analysis by special education status.*** Learning gains in the overall group were also explored by comparing general education students with special education students who followed an Individual Educational Plan. Significant differences were observed between classified and non-classified students in the overall group with a weak effect size ( $F(2, 103) = 4.03, p = .045, d = 0.09$ ). This indicated special education students were not as successful as general education students in the treatment and comparison classes. However, special education students in the infusion class ( $M = 5.90, SD = 1.98$ ) obtained similar scores to special education students in the comparison class ( $M = 5.97, SD = 1.74$ ), indicating that infusion did not impede learning acquisition. Other mean scores by subgroup included: general education,

infusion ( $M = 6.96, SD = 1.82$ ); and general education, comparison ( $M = 6.70, SD = 1.89$ ). There was no interaction effect between special education status and group.

***Summary of science content knowledge results.*** Table 11 summarizes the ANCOVA results for the main effect of treatment, as well as results when comparing integrated science learning scores in the overall group among several demographic subgroups: gender, SES, ethnicity, English language proficiency, and special education status. Infusion students outperformed comparison students on the post-science content assessment, and females outperformed males in the overall group. General education students performed higher than special education students in the overall group. No other differences were observed between subgroups in the infusion and treatment classes. Descriptive statistics for infusion subgroup analyses are summarized in Table 12.

Table 11

*Analysis of Covariance (ANCOVA) for Science Content Assessment*

Variable(s)	<i>F</i>	Significance	Partial eta squared $\eta_p^2$ (Cohen's <i>d</i> )
Science pre-test score	68.99	<0.001**	0.039
Grade 7 math score	136.84	<0.001**	0.075
Infusion (1)	17.02	<0.001**	0.010 (0.20)
Gender (2)	22.49	<0.001**	0.013 (0.23)
Free lunch (3)	0.97	0.325	0.001
Ethnicity (4)	0.038	0.845	0.000
English language proficiency (5)	0.031	0.861	0.000
Special education status (6)	4.03	0.045*	0.002 (0.09)
(1) * (2)	0.84	0.360	0.001
(1) * (3)	0.13	0.715	0.000
(1) * (4)	0.43	0.512	0.000
(1) * (5)	0.73	0.392	0.000
(1) * (6)	1.04	0.309	0.001

\**p* < .05, \*\**p* < .001

Table 12

*Descriptive Statistics of Subgroup Science Content Scores*

Demographic subgroup	Infusion scores	Standard deviation	Comparison scores	Standard deviation
Female	7.01	1.80	6.93	1.76
Male	6.63	1.84	6.33	1.97
High SES	6.84	1.86	6.64	1.85
Low SES	6.76	1.85	6.66	2.00
White	6.71	1.68	6.49	1.71
Non-White	6.32	1.69	5.91	1.72
Non-LEP	6.90	1.86	6.29	1.82
LEP	5.78	1.85	6.65	1.89
General education	6.96	1.82	6.70	1.89
Special education	5.90	1.98	5.97	1.74

**Individual teacher impacts on student performance.** To strengthen indications of programmatic effectiveness, additional data were generated to examine whether specific teacher impacts were confounding student-level results in the infusion group. Fifteen of the teachers who participated in the study taught infusion students; some also taught comparison classes and other teachers solely taught comparison classes. Descriptive statistics on mean post-integrated science assessment scores for individual teachers are summarized in Table 13. No major differences in mean post-integrated science content score were observed, suggesting there were no teacher outliers skewing the overall results for student achievement.

Table 13  
*Descriptive Statistics of Participating Teachers and Student Integrated Science Performance*

Teacher	Mean post-integrated science content score	Standard deviation	Number of infusion students
1	6.24	1.84	94
2	6.22	1.67	81
3	6.78	2.34	40
4	6.90	1.55	67
5	6.79	1.72	163
6	6.74	1.50	115
7	6.02	2.26	62
8	6.75	1.44	68
9	7.24	1.71	70
10	7.26	2.05	85
11	7.31	1.47	95
12	9.84	1.08	44
13	7.06	1.48	81
14	5.90	1.74	112
15	7.60	2.02	68
Total	6.86	1.88	1245

**Lesson analysis of student performance on thermal conduction assessment.** At the study location on Long Island, New York a pre-test was given to a group of infusion and comparison students prior to the lesson on thermal conduction (Appendix B). Since this lesson was administered toward the end of the academic year, the infusion group was taught the lesson

with all three MiSP stages of the mathematics. The comparison group was taught the lesson without the graphing component. Following the 5-day lesson, the same test was administered as a post-assessment to both groups. The sample included 30 students in the comparison group and 106 students in the infusion group. A Pearson correlation was calculated to determine the relationship between pre-test scores and scores on the post-test. Among the 136 students in this study, scores were significantly, positively correlated ( $r = .33, p < .01$ ), indicating that students who scored low on the pre-test also scored low on the post-test, in comparison to their peers; this indicated the usefulness of pre-test scores as the covariate in the ANCOVA analysis. Descriptive statistics for the infusion and comparison groups and their pre- and post-assessment scores are in Table 14. Although comparison students scored lower on the post-test than the pre-test, this was not a significant difference in a general linear model ( $F(2, 29) = 2.33, p = 0.14$ ).

Table 14

*Descriptive Statistics of Students Participating in Thermal Conduction Unit*

Group	Mean raw score	<i>n</i>	Standard deviation	Standard error
Pre-comparison	7.37	30	2.48	0.45
Pre-infusion	6.50	106	2.54	0.25
Post-comparison	6.87	30	3.05	0.56
Post-infusion	10.03	106	2.87	0.28

An ANCOVA was conducted with the lesson study sample, revealing that treatment group content scores were significantly higher when controlling for pre-test score with a very large effect size (Table 15). This significant result was consistent with previous results for the larger program sample though the effect size was much higher. However, gender was not a significant independent variable for the overall group, and no interaction effect was observed indicating that the treatment worked equally well for both males and females.

Table 15

*Analysis of Covariance for Lesson Analysis with Pre-Test as Covariate*

	<i>F</i>	Significance	Partial eta squared $\eta_p^2$ (Cohen's <i>d</i> )
Pre-test score	37.177**	0.000	0.228
Infusion (1)	49.980**	0.000	0.284 (1.26)
Gender (2)	1.096	0.297	0.009
(1) * (2)	1.234	0.657	0.002

\*\**p* < .001

#### **4.3 Research Question 2: Have Students' Attitudes Towards the Relationship Between Mathematics and Science Changed as a Result of Participating in the Infused Curriculum?**

A student attitudinal survey was created for this project based on previous MST programs (Appendix C). An exploratory factor analysis indicated that the questions converged into 2 factors - confidence and agreement – as described in Section 3.5. There were 5 questions categorized as confidence - these questions included how well students believed they could: 1) correctly construct a graph; 2) correctly label axes and title; 3) select the appropriate scale; 4) identify independent and dependent variables; and 5) answer questions about a graph. There were 2 science-related questions that were categorized as agreement: 1) Math is important for completing tasks in science, and 2) Being able to do math makes learning science easier. These questions were designed to see if students felt that mathematics was useful to the learning of science. The survey was given to the students at the same time points as the integrated content exam, that is, before the treatment in September and then again in May.

**Programmatic impacts on student confidence.** Using ANCOVA analysis with pre-test confidence score as a covariate, data showed that confidence levels of the infusion group ( $M = 8.49$ ,  $SD = 1.41$ ) were significantly higher than confidence scores in the comparison group ( $M =$

8.38,  $SD = 1.44$ ), though the effect size was weak ( $F(2, 447) = 8.62, p < .01, d = .11$ ). This finding indicated that after being exposed to a mathematics infused science curriculum the students in the treatment group increased their confidence in performing integrated science tasks slightly more than the comparison group. Results are summarized in Table 16.

Table 16

*ANCOVA for Student Confidence with Pre-Confidence Score as Covariate*

Variable(s)	$F$	Significance	Partial eta squared $\eta_p^2$ (Cohen's $d$ )
Pre-test confidence score	669.54**	<0.001**	0.221
Infusion (1)	8.62*	<0.003*	0.003 (0.11)

\* $p < .01$ , \*\* $p < .001$

**Programmatic impacts on student agreement.** When examining the agreement composite on the attitude survey, ANCOVA with pre-agreement score as the covariate revealed the infusion group showed significantly higher scores ( $F(2, 447) = 106.38, p < .001$ ), that is, they recognized the value of mathematics in helping them understand integrated science concepts. Data showed that agreement levels of the infusion group ( $M = 3.47, SD = 1.03$ ) were significantly higher than agreement scores in the comparison group ( $M = 2.97, SD = 1.01$ ). There was a small to medium effect size for the infusion treatment over the comparison group ( $d = 0.40$ ). Results are summarized in Table 17.

Table 17

*ANCOVA of Student Agreement with Pre-Agreement Score as Covariate*

	$F$	Significance	Partial eta squared $\eta_p^2$ (Cohen's $d$ )
Pre-test agreement score	445.05	<0.001**	0.179
Infusion (1)	106.38	<0.001**	0.039 (0.40)

\* $p < .01$ , \*\* $p < .001$

#### **4.4 Research Question 3: How Do Students' Views on Integration Correlate with their Performance on an Integrated Science Assessment?**

Along with the integrated science content exam, students were given the attitudinal survey to answer Likert questions on their confidence on integrated science skills and agreement regarding the utility of learning mathematics in science. These questions were identical to the survey they were given in the beginning of the year. Correlations to the integrated science content scores were then examined. All correlations of student attitude were statistically significant at the  $p < .01$  level and showed correlations between student confidence ( $r = .29$ ,  $N = 2023$ , moderate effect) and their scores on the integrated content exam, as well as for student agreement and their scores on the integrated content exam ( $r = 0.19$ ,  $N = 2113$ , small effect). Sample sizes were larger in this analysis since the population was not limited to those students with covariate pre-test and mathematics scores.

#### **4.5 Research Question 4: How Does Teacher Confidence Relate to Science Learning Outcomes and Student Attitudes?**

At the conclusion of the program infusion teachers were asked to complete an online survey rating their confidence in achieving certain program related goals (Appendix D). Teachers self-rated their confidence in the following areas: 1) infusing mathematics into science; 2) enhancing the mathematics taught; 3) helping to make mathematics more meaningful to students; and 4) promoting positive attitudes about mathematics. Using these 4 items, a composite score was calculated with high internal consistency ( $\alpha = .91$ ). Teacher confidence was positively correlated with student confidence ( $r = .14$ ,  $N = 1756$ ) and agreement ( $r = .085$ ,  $N = 1786$ ) with small effect sizes. However, teacher confidence was negatively and weakly correlated with student achievement on the integrated content assessment ( $r = -.094$ ,  $N = 2025$ ). Sample



sizes were larger in these analyses since the population was not limited to those students with covariate pre-test and mathematics scores. The values of the correlations indicate explanatory power for less than 2% of the variance, indicating no effect for practical purposes. These results are summarized in Table 18.

Table 18

*Correlations Between Teacher Confidence and Student Measures*

	Teacher confidence	Student content	Student confidence
Teacher confidence	1.00		
Student content	-0.094*	1.00	
Student confidence	0.14*	0.39*	1.00
Student agreement	0.085*	0.19*	0.28*

\* $p < .01$

#### 4.6 Summary of Results

Results indicated several notable findings when exploring the effect of the mathematics-science integrated curriculum on student achievement and attitudes, as well as the relationship between teacher confidence and student performance. Overall, participation in the mathematics-science infusion curriculum promoted improvement in student learning and attitudes, which were correlated to each other. The relationship between teacher confidence and student gains in knowledge and attitudes were weakly correlated and the results somewhat inconclusive.

**Research question 1: Have students’ understandings of integrated science content improved as a result of the infused curriculum?** This research question examined the integrated content knowledge scores of the infusion middle school students when compared to a similar control group; in addition, the achievement of demographic subgroups was compared

within the overall group. The infusion students outperformed the comparison group with a small effect size ( $d = .20$ ), and female students outperformed male students with a small effect ( $d = .23$ ). Also, general education students outperformed special education students with a weak effect ( $d = .09$ ). There were no differences among high and low SES groups, White and non-White students, and LEP and non-LEP students in the infusion and treatment classes. A second sample of students was tested on one unit within the curriculum – thermal conduction. Infusion students also outperformed the comparison group with a large effect ( $d = 1.26$ ), though there was no significant difference between male and female student performance.

**Research question 2: Have students’ attitudes towards the relationship between mathematics and science changed as a result of participating in the infused curriculum?**

This research question explored differences in the attitudes (confidence and agreement) of middle school students in the infusion and comparison classes. With regard to confidence, infusion students scored higher than comparison students with a weak effect size ( $d = .11$ ). With regard to agreement, the infusion group scored higher than the comparison group with a small to medium effect size ( $d = .40$ ).

**Research question 3: How do students’ views on integration correlate with their performance on an integrated science assessment?** This research question examined correlations between student content performance and their attitudes towards mathematics-science integration. There was a correlation between science achievement and confidence with moderate to large effect ( $r = .39$ ,  $N = 2023$ ), and a correlation between science achievement and agreement with mathematics utility with a small to moderate effect ( $r = .19$ ,  $N = 2113$ ).

**Research question 4: How does teacher confidence relate to science learning outcomes and student attitudes?** This research question addressed whether there were correlations between teacher confidence and student outcomes. Teacher confidence was weakly and negatively correlated with student integrated science achievement ( $r = -.094, N = 2025$ ). Also, teacher confidence was weakly correlated with student confidence ( $r = .14, N = 1756$ ) and student agreement ( $r = .085, N = 1786$ ). Effect sizes were negligible indicating no relationship between teacher confidence and student outcomes.

## Chapter 5

### Conclusions, Implications and Recommendations

#### 5.1 Introduction

This study was an examination of the effectiveness of a mathematics infused science program for middle school students in various regions of New York State. Integrated STEM curricula have been shown to improve science and mathematics achievement as well as student attitudes (Furner & Kumar, 2007). When students apply mathematical reasoning in consistent, meaningful ways, they have been more likely to recognize its relevance in science and to make deeper connections between these disciplines (Venville, Wallace, Rennie, & Malone, 2000; Wilkins, 2000). The findings in this study provide support for the replication of such programs to serve children in diverse educational settings.

Integrated content test scores and student and teacher attitudes were analyzed to assess the impacts of this pedagogical innovation in instruction in a large-scale study. The purpose of this chapter is to review the findings from the research and discuss conclusions from the data analysis (5.2). Strengths and challenges of the infusion curriculum and its implementation are identified (5.3). A discussion of implications and recommendations are provided (5.4). This chapter concludes with a summary (5.5).

#### 5.2 Main Findings and Discussion

The major findings of the study will be discussed in terms of measurable impacts on the two major stakeholders: middle school students and their teachers. These two perspectives are

consistent with Berlin & White's (1993) model of mathematics-science integration. As discussed in Chapter 2, Berlin and White identified several benefits of mathematics-science integration, primarily, that integration helps students form deeper understandings between concrete and abstract representations. As this study has indicated, students may also develop an appreciation for the use of data, which in turn improves their interest and motivation in STEM disciplines in school. Berlin and White also advocated a student-centered, integrated curriculum to enhance reasoning skills such as organizing data, developing models, and interpreting graphs – these skills and others were assessed with the Integrated Science Content Knowledge Assessment (Appendix A). Berlin and White's framework also theorized that students' attitudes towards integration would influence their ability to think logically when learning science.

To achieve the goals proposed by Berlin and White (1993, 1994, 1995, 2001, 2010), the National Academy of Sciences (2014), the National Research Council (2011, 2012), and other researchers, professional development is necessary to train teachers in implementing effective STEM integration. Professional development that models innovative teaching strategies in authentic contexts is necessary for students to acquire the skills to understand STEM connections. This training should be intensive, sustained, and measured by valid and reliable assessments. Although students in the infusion group indicated significant gains in knowledge and attitudes when compared to students in the comparison group, there was effectively no measurable relationship between teacher confidence and student outcomes.

**Impacts on student content knowledge.** The results of the statistical analyses suggested inferences supporting positive programmatic impacts. Using instruments with high quality items, as suggested by the National Academy of Sciences (2014) in the conceptual framework, integrated science achievement was compared between students in the treatment and comparison

classes. Students in the infused classes performed significantly higher on the integrated content assessment than students in the comparison classes. The effect size ( $d = .20$ ), though small, is considered to be notable (that is, equal to or greater than 0.20) when evaluating large-scale programs and their potential for systemic educational reform (Hedges & Hedberg, 2007). This suggests the MiSP Program has tremendous potential for transforming science learning for middle school students on a large scale.

Several demographic subgroups were explored within the overall group to assess differential impacts and provide more nuanced analyses. Females scored significantly higher than males in the overall group when controlling for pre-test scores in science and mathematics. Females scored higher on the pre-tests than males, and their higher performance continued with the post-tests. This suggests that the integrated curriculum model may be useful for promoting self-efficacy among young women during critical years in academic formation. Science self-concept, a student's perception of her skills with the domain, is influenced by performance in science relative to one's peers (Hardy, 2014). Females' superior achievement may lead them to view themselves as scientists and encourage them to persist in STEM in later years (Virnoche, 2008). However, it is important to note that the treatment was equally effective for male and female students.

Another finding regarding subgroup performance revealed that general education students performed better than special education students. This is not surprising given the test-taking difficulties often experienced by students with individualized education plans. Special education students in the infusion and comparison classes performed statistically at the same level on the post-content assessment. It should be noted that although these students were designated as special education students with IEPs that would entitle them to testing

modifications for school and state based assessments, no accommodations were implemented for these assessments. One positive aspect of this finding is that participation in the infused curriculum was not harmful for classified students. Future integration studies should examine differentiated instruction and more flexible assessment strategies, including providing these students with their testing modifications in research settings, that may level the playing field for special education students; inquiry-based approaches and performance assessments have been shown to improve the learning of science content for this population (Mastropieri et al., 2006).

With regards to other subgroups, there were no statistical differences in science performance. This shows that students in the overall group performed equally as well as their counterparts, regardless of English proficiency, ethnicity, and socioeconomic status. These particular demographic identifiers have frequently appeared when discussing chronic inequities in the U.S. educational system (for example, Lee, 1998; Tate, 2001). The MiSP Program shows great promise in improving science learning for traditionally underserved students who are underrepresented in STEM disciplines; this suggests the program is not only innovative but can provide more socially just educational opportunities for middle school students. Anecdotally, teachers reported that ELL students displayed more confidence during the implementation of the infused lessons and attributed this increase to having these students use their mathematical ability rather than struggling with reading comprehension. Future research should address this question in greater depth with a larger sample size of ELL students.

In the smaller group who participated in the thermal conduction unit, the infusion group also scored higher on the integrated science assessment, this time with a large effect size ( $d = 1.26$ ). These results demonstrate that the treatment was a highly effective curricular reform to improve middle school science achievement, complementing previous published work on the

same MiSP Program that reported improved mathematics performance (Burghardt et al., 2015). These results add an interesting insight to the larger sample results. The choice of the months of September and May to measure student performance on the overall pre-/post-content assessment was a relatively long duration, whereas the time frame from pre- to post-lesson assessment was only approximately 5 school days, administered prior and then just after the completion of the lesson. This suggests that if the treatment were done more consistently and seamlessly throughout the year rather than just 6 lessons in 1 year, the pre-/post-differential for the entire academic year would be higher with greater effect size. Although the learning objectives for the thermal conduction unit were primarily science-related, mathematical applications were made wherever possible; this strategy could be implemented throughout the entire 8<sup>th</sup> grade science curriculum to maximize student achievement and scientific literacy. The smaller group results are also notable in that these students all attended the same middle school so differences in demographic and academic preparation characteristics were minimized. The infusion and comparison students experienced the same overarching science curriculum with only one difference – mathematics-science integration vs. the traditional curriculum. Consequently, the results from this subgroup analysis are quite promising for the potential of the integrated curriculum to have substantial impact on science learning in middle school classrooms.

**Impacts on student attitudes.** According to the quantitative results, students in the infusion class had more confidence in their integrated science ability than students in the comparison class, though the effect size was weak ( $d = .11$ ). This finding may be explained when considering the requirements of the integrated curriculum – students may have felt only marginally more confident because of the perceived difficulty of the required assessment tasks. This may speak to the metacognition of the students within an infusion class taking their



mathematical ability into account when rating their confidence within an infused curriculum. That is, they were aware of the cognitive demands and evaluated their own ability in light of the challenging mathematical applications. Additionally, students had no knowledge of their pre-/post-assessment scores and therefore did not have a sense of the learning gains they achieved. Sharing feedback from the assessments with students may enhance their confidence and science self-concept.

When considering the utility of an integrated curriculum, defined as agreement in this study, students in the infusion class expressed more agreement than the comparison class with a small to medium effect size ( $d = .40$ ). The MiSP Program was considerably effective in helping middle school students recognize the intrinsic value of mathematics in learning scientific principles. Again, this shows significant promise for students as they enter secondary education. Understanding the value of mathematics may encourage them to make choices consistent with this view, for example, choosing science and mathematics electives in high school beyond what is required for graduation. These longitudinal academic behavioral patterns are worthy of further study.

**Relationship between student content knowledge and student attitudes.** Berlin and White (1993) highlighted the need to expose students to new ways of learning and knowing through the introduction of cross-curricular process skills in problems solving. They proposed that doing so would result in improved student attitudes and perceptions towards mathematics and science. Data from this study revealed that performance and attitudinal constructs are positively related. Correlations between student attitudes and content knowledge were statistically significant, with measured correlations between student confidence and their scores on the integrated content exam ( $r = .39$ ,  $N = 2023$ , moderate to large effect), as well as for

student agreement and their scores on the integrated content exam ( $r = 0.19$ ,  $N = 2113$ , small to moderate effect). The statistically significant improvements of science achievement, confidence and agreement in the infusion group over the comparison group support the notion that early exposure to an infused curriculum impacts students' performance in and attitudes towards science. Higher science performance often results in improved confidence and science self-concept (Britner, 2008), and the results from this study suggest that students taught in a mathematics-science integrated curriculum are likely to see both improved achievement and attitudes. This result indicates that integrated STEM curricula has the potential to improve science confidence at a pivotal point in children's lives, when their future career perceptions are germinating and influencing future academic choices. Middle school curricular innovations that improve self-efficacy have the potential to expand the STEM pipeline, particularly for young girls who have been traditionally underrepresented in scientific disciplines (Britner & Pajares, 2001).

**Relationship between teacher confidence and student outcomes.** Teachers had positive views regarding infusion and their confidence in teaching the curriculum, according to the teacher survey. However, numerous studies and reports have highlighted the weakness of teacher confidence as a proxy for measuring successful professional development programs (National Academy of Sciences, 2014). This study, though emphasizing student outcomes, measured teacher confidence to provide an additional measure of programmatic success. Teacher confidence was negatively and weakly correlated to student achievement on the integrated content assessment ( $r = -.094$ ,  $N = 2025$ ), and positively and weakly correlated with student confidence ( $r = .14$ ,  $N = 1756$ ) and agreement ( $r = .085$ ,  $N = 1786$ ). Self-reported teacher confidence explained less than 2% of student variance. This suggests that self-reported teacher

confidence data is not a reliable indicator of the success of educational reforms. Student outcomes must have reliable, objective measures, and these outcomes provide the basis for evaluating the effectiveness of teacher professional development. This has been suggested by the NAS Report on STEM Integration (2014), which implied that self-reported teacher data is a weak measure of programmatic effectiveness.

These results also suggest that fidelity of implementation should be directly observed in similar integration programs. More confident teachers may not feel obligated to teach the integrated lessons with the consistency required for full impact. Mathematics-science connections that may appear obvious to teachers often are not obvious to students at this level. More confident teachers may not make the connections explicit to students which may have an impact on achievement. Further research could explore classroom practices and teachers' content knowledge to determine conformity with prescribed lesson plans and how this may affect student learning and performance.

### **5.3 Strengths and Challenges of the Infusion Curriculum**

This study of middle school mathematics-science integration had many strengths that set it apart from prior research in curriculum integration. First, the MiSP Program has established a large scale, replicable model for professional development in mathematics-science integration to improve middle school science learning and student attitudes. The long-term, sustained, professional development model resulted in fairly consistent results among classes taught by 28 teachers in a variety of classroom settings. Student outcomes were measured and indicated improvements in science mastery and positive attitudes when comparing infusion students to the comparison group. Secondly, it is important to note that this research provides the empirical data that has been missing from many previous studies. The assessment tools that were administered

were specific in assessing the objectives for an integrated curriculum, namely, that the questions asked required students to apply skills in one discipline (mathematics) for problem solving in another discipline (science). Such contextualized applications have been shown to improve learning in science. In addition, correlations among student achievement and student attitudes were analyzed to provide more substantive support for program quality than has been typically reported in science education literature. Other studies have relied upon self-reported teacher data or anecdotal data as weak measures of programmatic success. The results from this study demonstrated that such self-reported teacher confidence data might not correlate to student outcomes, further emphasizing the need for robust measures of student outcomes to justify resources for large-scale curricular reform.

Additional challenges of the mathematics-science curriculum reform were also identified. First, the infusion strategy was implemented during six distinct units throughout the academic year. The application of specific mathematical tasks during separate units may have been an unreliable approach. Although this strategy did result in improved student outcomes, perhaps a more consistent infusion structure may have further improved student outcomes, as shown in the lesson study. Teachers were trained to apply the three stages of mathematical graphing skills in specific units, but a more comprehensive strategy may have been to train teachers to seamlessly integrate mathematics throughout the entire intermediate curriculum.

A second limitation was the voluntary nature of program participation. Administrators expressed interest in MiSP and recommended specific teachers for the program, who were compensated for the considerable time spent in professional development during the summer and academic year. A more systemic approach would have been to train all of the middle school science teachers within specific schools or districts. District-wide curriculum reform efforts have

been shown to be more effective by establishing a culture of support and buy-in among participating teachers, as well as administrative support for collaborative planning and required resources.

A final challenge was the inconsistent variation in teacher confidence in program implementation. Teachers' confidence was not correlated in a meaningful way to improved student outcomes. This indicated that teachers might need better self-assessment mechanisms for their professional effectiveness. These mechanisms may include more frequent formative measurement of student progress, direct observation and peer and/or administrative coaching to improve fidelity of curricular implementation, and continued training in mathematics content and its infusion into the learning of science concepts.

#### **5.4. Implications and Recommendations**

The recommendations proposed by the National Academy of Sciences (2014) on STEM integration, the philosophy behind NGSS and the CCSS, and the writings of Berlin and White guided this study and provided the parameters for analyzing the empirical data. The purpose of this study was to examine infused STEM settings in middle school classrooms and the impact this intervention had on student integrated science content knowledge and student and teacher attitudes. The study suggested that an infused curriculum is a worthwhile strategy to improve achievement in middle school science, as well as to increase student confidence and agreement with the utility of an integrated science-mathematics approach to problem solving. Research has indicated that teacher quality is the biggest determinant of student engagement in science (Osborne, Simon & Collins, 2003), and it is necessary for teachers to accurately gauge their

professional strengths and weaknesses. Although teachers reported confidence in their ability to present an integrated curriculum, this was not supported by student performance.

If policymakers are determined to foster twenty-first century learning environments in STEM disciplines, then changes should be made to curricula to include more integrative approaches to teaching and learning. Pre-service and in-service teachers need to have more access to professional development in integration to increase their pedagogical content knowledge in mathematics and science. As teachers become more skilled in both science and mathematics pedagogy, they will be able to provide the foundational supports needed for students to succeed in an integrated class. They will also convey the necessity of an integrated curriculum in understanding scientific principles as they apply to the everyday world. Collaborative training in authentic contexts is a promising strategy for STEM teachers to promote higher order thinking skills.

Developers of integrated curricula need to address the preparation of educators to implement reforms successfully. Expanding the knowledge base of teachers is essential in delivering an integrated curriculum. Pre-service programs need to provide integrative curricular experiences so novice teachers are skilled at delivering the supports needed to make the connections among disciplines obvious to students. To this end, periodic joint meetings with science and mathematics pre-service teachers led by experienced mathematics and science methods faculty can facilitate dialogue that would highlight areas of overlap between the disciplines, particularly in process skills. In addition, the ability to identify different discipline specific conventions is necessary to expand teachers' content knowledge. This approach will allow teachers to become aware of the scope and sequence of instruction for the other discipline.

Additional research is required on how to present integrated experiences to students of various learning abilities and how to develop teachers' skills to do so. Professional development opportunities need to be in place for lesson studies examinations, designed for teachers to review lessons with their colleagues and make mathematics-science connections. The availability of standards-based, teacher-friendly integrated lesson plans can also facilitate the ability to integrate science and mathematics.

While middle school is the suggested level for curriculum integration, it is also the beginning of separate disciplines taught in separate classes, thus scheduling limits the ability to integrate disciplines due to time constraints and lack of common planning with other teachers. These limitations may be a reason students do not see the usefulness of an interdisciplinary approach. Block scheduling of mathematics and science may allow more instructional time for integrative teaching and learning. Since this program has been shown to be effective in middle school classrooms, STEM disciplinary integration should also be a goal for enacted curricula in elementary and high schools. This will allow for continuity in ways of thinking and learning. Enacting reforms at different points along the STEM pipeline will help increase interest and participation in STEM study and careers. Also, students will improve their scientific literacy if challenged to process new knowledge through interconnected patterns and relationships.

Literature has suggested that STEM education may positively influence STEM interest, particularly for traditionally underserved populations. Seventy-five percent of 8<sup>th</sup> grade students are not proficient in mathematics (NCES, 2000), and these students are then unprepared for the demands of higher level mathematics and science courses. More rigorous preparation for middle school students would help mitigate this chronic problem and expand the STEM pipeline. Many government sponsored programs have proposed goals to increase the amount of students who

pursue advanced degrees and careers in STEM, especially among women and underrepresented minorities, and ultimately increase the talent pool of the STEM workforce. Therefore, future research on integrated mathematics-science curriculum should examine student interest and performance longitudinally.

## **5.5 Summary**

The researcher's purpose in this study was to examine the infusion of mathematics into middle school science classes. To determine if there were positive associations with the infusion model, performance on integrated content assessments and responses to attitude surveys were examined. The conceptual framework guiding this research suggested teaching an integrated mathematics and science curriculum in a middle school science class promotes critical thinking and problem solving skills and enables students to see the utility of a multidisciplinary approach to problem solving. From what we currently know about cognition and learning, integration is the preferred method of learning as our brain makes connections for improved problem solving. Deeper understanding and meaningful learning occurs when students make connections among ideas.

Historically, rigor in science has been determined by the amount of discrete knowledge a student has in order to pass a class or a final exam. These discipline-specific tests may have been a limitation to adopting an integrative pedagogy, however, through the adoption of CCSS and NGSS in many states, students will be increasingly assessed on science practices and process skills in addition to disciplinary knowledge. This new emphasis on reasoning and applications that utilize mathematical tools within a science context further supports the research findings of infusion as an innovative, promising approach in STEM education reform.



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## Appendix A: Student Content Knowledge Assessment

MISP STUDENT ID NUMBER

Teacher:

Period:

Date:

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Complete the following questions to the best of your ability. When given choices, circle the correct letter. When asked to write your answer, show *ALL* of your work.

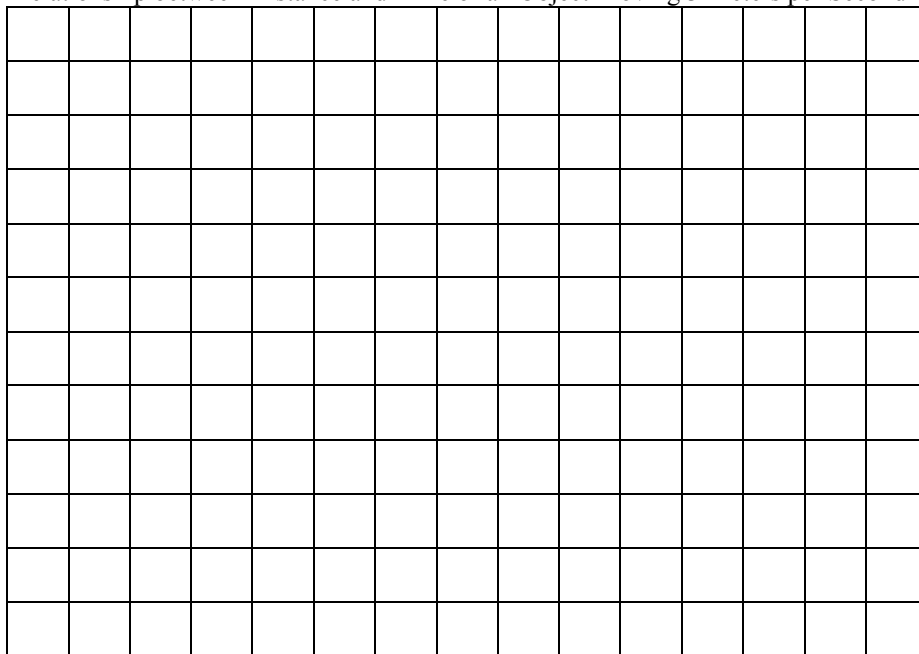
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1. The table below shows the distance and time of an object moving 3 meters per second.

<b>Time (seconds)</b>	0	1	2	3	4	5
<b>Distance (meters)</b>	0	3	6	9	12	15

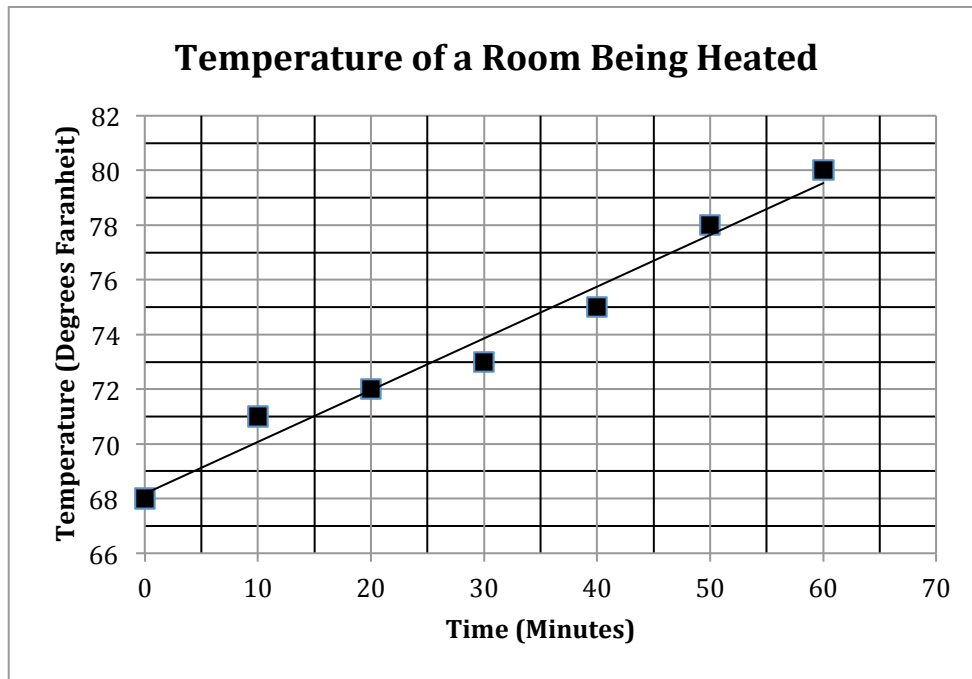
*Graph the data below. Be sure to label each axis and provide the unit of measurement.*

Relationship between Distance and Time of an Object Moving 3 Meters per Second



- Label the axes.
- Use a correct scale.
- Make sure the data fits the scale.
- Plot the data.

2. The graph below shows the temperature of a room being heated for sixty minutes.



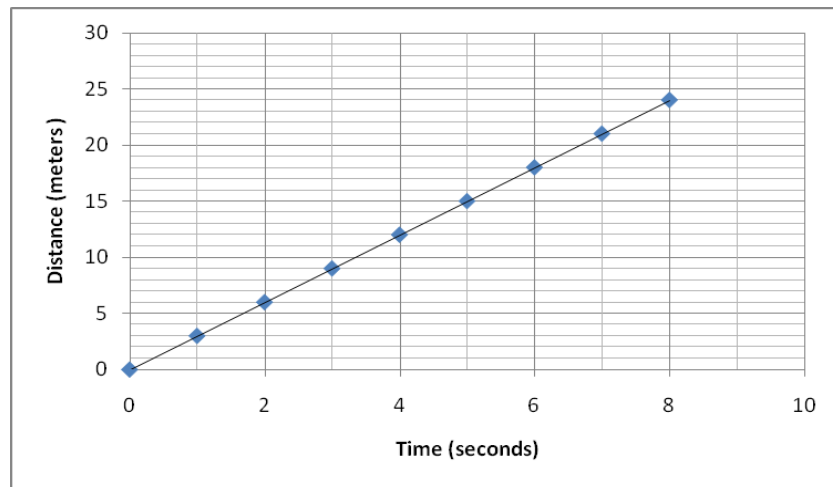
a) What is the temperature of the room at 25 minutes?

- |               |               |
|---------------|---------------|
| a) 68 degrees | b) 73 degrees |
| c) 74 degrees | d) 72 degrees |

b) What is the slope (unit rate of change) of the line in the graph (please show your work)?

- |                          |                          |
|--------------------------|--------------------------|
| a) 5 degrees per minute  | b) 2 degrees per minute  |
| c) 0.5 degree per minute | d) 0.2 degree per minute |

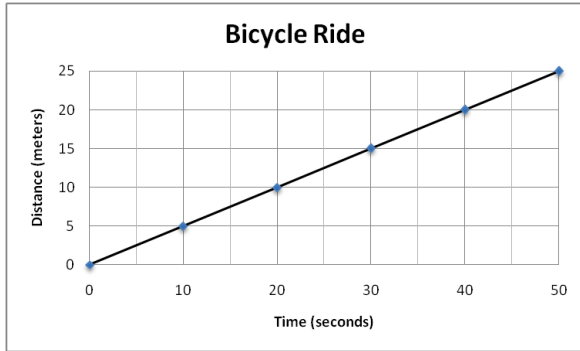
3. Below is a data table and graph for distance and time of an object moving at a constant speed.



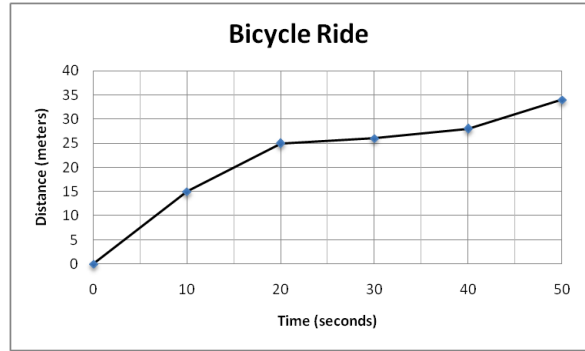
- a) After 3 seconds, what is the change in distance (in meters)?
- a) 9 meters
  - b) 0 meters
  - c) 3 meters
  - d) 1 meter
- b) If the rate of speed were 10 meters per second, the slope (unit rate of change) of the line would be:
- a) Steeper
  - b) The same
  - c) Less steep

4. The following four graphs all represent the relationship between the distance of a bicycle ride and time. Circle the graph that indicates the greatest slope (unit rate of change) between 30 and 40 seconds?

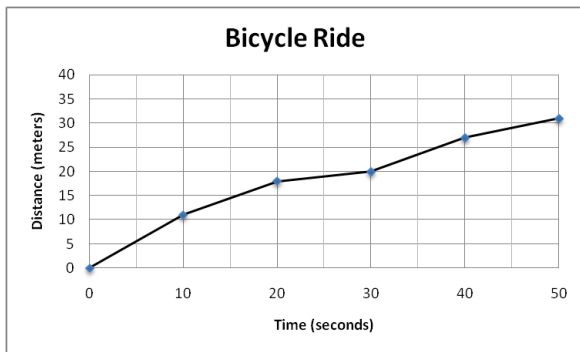
Graph A.



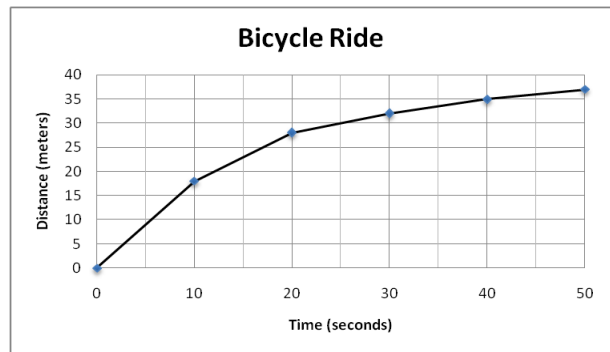
Graph B.



Graph C.

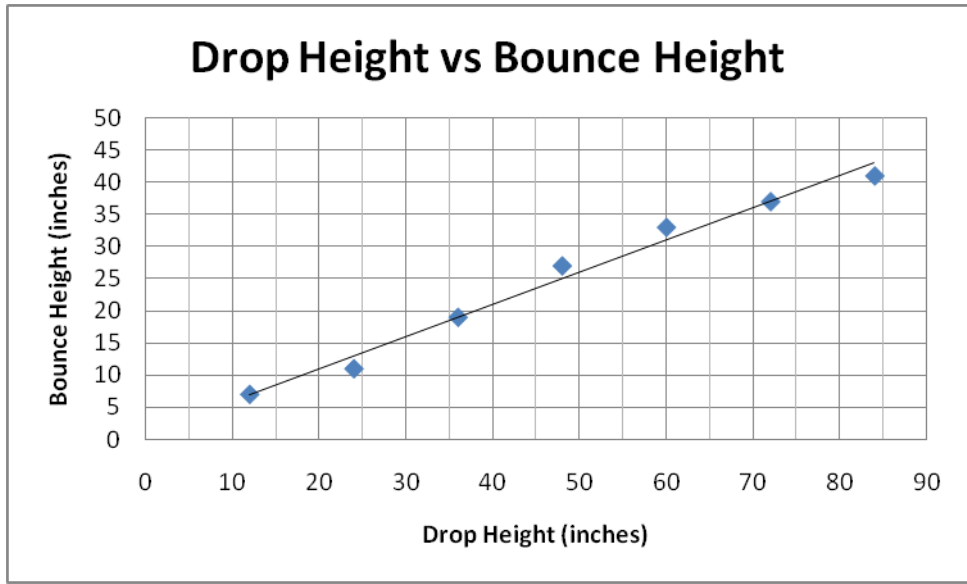


Graph D.



A class completed an experiment to see the relationship between the drop height of a rubber ball and how high the ball bounced. They recorded their data in the table below. They also graphed the data and drew a line of best fit.

Drop Height (inches)	Bounce Height (inches)
12	7
24	11
36	19
48	27
60	33
72	37
84	41



5. Based on this graph, approximately how high would you expect a ball dropped from a height of 40 inches to bounce?
- a) 40 inches
  - b) 21 inches
  - c) 20 inches
  - d) 25 inches

6. Is a bounce height of 70 inches is a good prediction for a drop height of 110 inches?

Circle an answer:                  yes                                  no

Explain your answer.

---



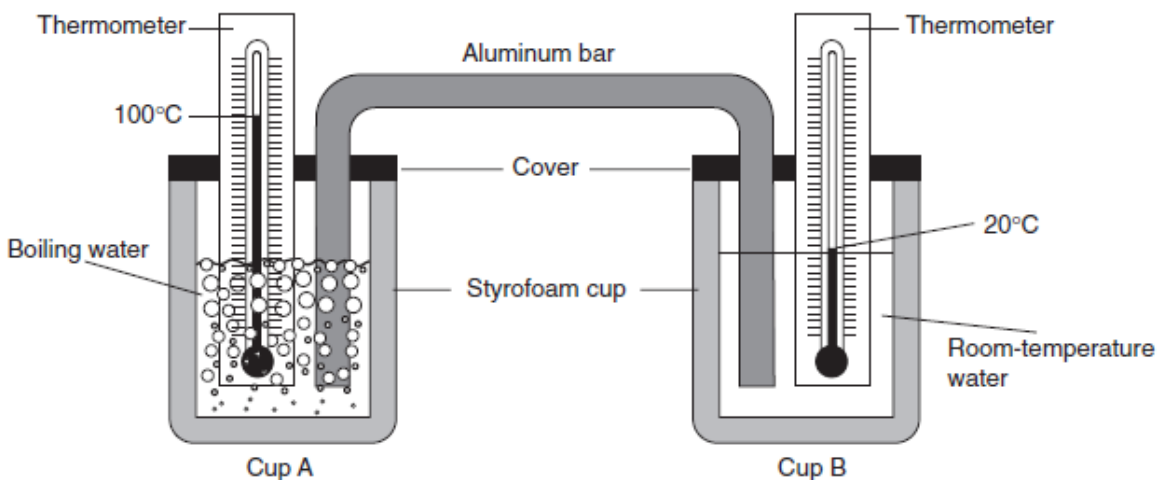
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## Appendix B: Thermal Conduction Lesson Assessment

Number \_\_\_\_\_ Teacher \_\_\_\_\_ Period \_\_\_\_\_

Questions 1-4 Write True or False on the line. If you wrote False, correct the sentence to make it true.

1. Conduction can only take place when objects are touching. \_\_\_\_\_
2. A good insulator minimizes the amount of heat loss. \_\_\_\_\_
3. Heat moves through liquids and gases by conduction. \_\_\_\_\_
4. Metals are good insulators of heat. \_\_\_\_\_



If you were to graph the temperature change in Cup A and Cup B, what would be the sign of the slope of each?

5. Cup A \_\_\_\_\_ (positive, negative or zero)
6. What does that tell you about the changes in temperature as time passes?

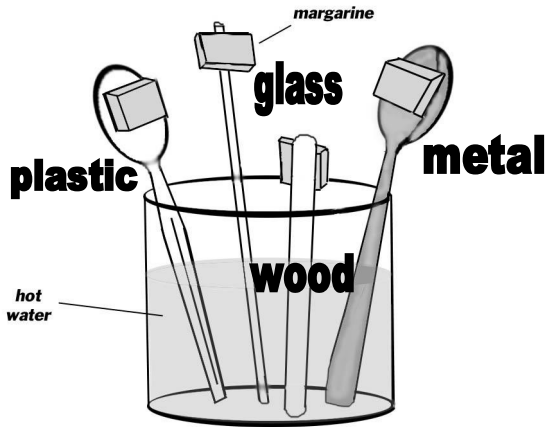
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7. Cup B \_\_\_\_\_ (positive, negative or zero)
8. What does that tell you about the changes in temperature as time pass?

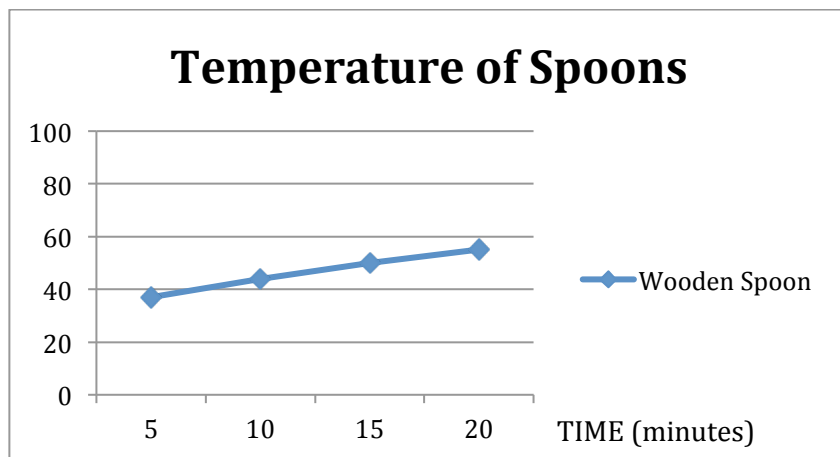
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9. On which spoon would the margarine melt the fastest? \_\_\_\_\_

If there were thermometers attached to each spoon and the temperature on each spoon was measured every 5 minutes, a graph could be constructed like the one below.



10. Draw a line on the graph showing where the metal spoon would be in relation to the wooden spoon.

11. What does the slope tell you about the conductivity of metal?

\_\_\_\_\_

12. From the graph, which spoon is the better insulator? (Wood or Metal)

\_\_\_\_\_

13. Explain:

\_\_\_\_\_

### Appendix C: Student Attitude Survey

**Please rate your level of confidence with the following items:**

	<b>Not at all confident</b>								<b>Highly Confident</b>	
	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>
Selecting appropriate scale for a graph.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>
Answering questions about a graph.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>
Correctly constructing a graph.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>
Correctly label graph axes and titles.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>
Identify the independent and dependent variables.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>	<i>(6)</i>	<i>(7)</i>	<i>(8)</i>	<i>(9)</i>	<i>(10)</i>

**Please rate your agreement with the following items:**

	<b>Strongly Disagree</b>				<b>Strongly Agree</b>
	<b>(1)</b>				<b>(5)</b>
Math is important for completing tasks in science.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>
Being able to do math makes learning science easier.	<i>(1)</i>	<i>(2)</i>	<i>(3)</i>	<i>(4)</i>	<i>(5)</i>



## Appendix D: Teacher Survey (Online-Post Lesson)

### MiSP Weekly Survey

#### 1. MSTP Weekly Feedback Survey

**1. Your Name**

**2. Please indicate the dates (e.g. 9/24 - 9/28) of the lesson you taught.**

**3. Approximately how many hours (or minutes) of math did you teach this week?**

**4. What lesson did you teach?**

**5. Which level math did you cover?**

Level 1

Level 2

Level 3

**6. What math or science questions were raised by students?**

**7. When implementing the math infused lessons, what was most successful this week?**

**8. When implementing the math infused lessons, what did you have the most difficulty with this week, and/or what did not work?**

## MiSP Weekly Survey

**9. On a scale from 1 (Not at all Successful) to 3 (Moderately Successful) & (Very Successful), how would you rate the success of your lesson implementation at accomplishing each of the following THIS WEEK:**

	Not at all Successful		Moderately Successful		Very Successful
Infusing mathematics into science	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhancing the mathematics taught	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helping make mathematics more meaningful to students	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Promoting positive attitudes about mathematics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**10. Overall, how would you rate the lesson?**

- 1 (Poor)  
 2 (Fair)  
 3 (Good)  
 4 (Excellent)

**11. Do you believe students developed a deeper understand of the MATH concepts covered?**

- Yes  No

Please Explain:

**12. Do you believe students developed a deeper understanding of the SCIENCE or TECHNOLOGY concepts covered?**

- Yes  No

Please Explain:

**13. In general, what were students' reactions after completion of the lessons? (i.e., did they seem frustrated over lesson content, satisfied that they understood the content, etc)**

## MiSP Weekly Survey

14. Please describe any additional support you would like before the next lesson.