# The Effects of a Mathematics Infusion Curriculum on Middle School Student Mathematics Achievement

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*Increasing mathematical competencies of American students has been a focus for educators, researchers, and policy makers alike. One purported approach to increase student learning is through connecting mathematics and science curricula. Yet there is a lack of research examining the impact of making these connections. The Mathematics Infusion into Science Project, funded by the National Science Foundation, developed a middle school mathematics-infused science curriculum. Twenty teachers utilized this curriculum with over 1,200 students. The current research evaluated the effects of this curriculum on students' mathematics learning and compared effects to students who did not receive the curriculum. Students who were taught the infusion curriculum showed a significant increase in mathematical content scores when compared with the control students.*

Student competencies in mathematics and science have been a focus of both research and educational movements periodically over several decades. In the past 10 years, this focus is generated from dual pressing realities: the recognized necessity for high school graduates to grasp a sufficient mathematics and science knowledge foundation to be successful in college or employment (Patton, Cronin, Bassett, & Koppel, 1997; U.S. Department of Education, 2007), along with the recognized deficiencies in mathematics and science content knowledge of American students (Gonzales et al., 2009). For instance, a recent report from the National Mathematics Advisory Panel (U.S. Department of Education, 2008) noted that American students' mathematics achievement is below the level attained by students in other countries, stating that American students fall markedly behind once they reach late middle school.

One way to increase student competency in mathematics endorsed by both the National Council of Teachers of Mathematics and the National Science Teacher Association is to draw connections between science, technology, engineering, and mathematics (STEM) areas (National Council of Teachers of Mathematics, 2000; National Research Council, 1996). Interconnected curriculum is a pedagogical tactic that has been recognized for many years as an important teaching tool that supports student learning. It is believed that these connections aid in students' broader understanding and application of related concepts and ideas. Seamless connections can be made between science and mathematics, as both are utilized to discover patterns and relationships (Issacs, Wagreigh, & Gartzman, 1997), both are learned though similar processes (Bosse, Lee, Swinson, & Faulconer, 2010), and both use the scientific processes of inquiry and problem solving (Bosse et al., 2010; Pang & Good, 2000; Underhill, 1995). Thus, it is possible to create a connection between these two content areas within the classroom.

## Making Connections Between Science and Mathematics

Connecting science to mathematics curricula creates meaningful and stimulating learning experiences for students, allowing students to see the "big picture" and to recognize the importance of mathematics (Berlin & White, 1994; Frykholm & Glasson, 2005). It has also been argued that students become more interested in school when mathematics and science are connected or integrated in some way (Bragow, Gragow, & Smith, 1995; Czerniak, Weber, Sandmann, & Ahem, 1999; McComas, 1993). Making mathematical connections in science classes has been shown to enhance the understanding of mathematics, as well as to improve the perceptions students have about mathematics being a relevant and necessary component of their lives (Reed, 1995). In contrast, when the two subjects are taught separately the contextualization of the subject matter can be lost and students may be less likely to solve real-world problems (Frykholm & Glasson, 2005; Furner & Kumar, 2007).

For over a century, mathematics and science are two disciplines frequently viewed as logically connected and interrelated (Berlin & Lee, 2005; McBride & Silverman, 1991; Pang & Good, 2000). Berlin and Lee (2005) purported that references made to mathematics, and science integration can be documented from as early as 1901, and include numerous terms to refer to this connection, such as fused or interdisciplinary. Along with the multiple definitions, the approaches used to achieve a connection can vary in numerous ways. Hurley (2001) reviewed the literature on connecting mathematics and science and classified five different levels of integration. These include: (a) sequenced, when mathematics and science are planned and taught successively; (b) parallel, when both are planned and taught simultaneously through analogous concepts; (c) partial, when science and mathematics are taught together to some extent and partially as separate disciplines; (d) enhanced, when either science or mathematics is the major discipline, while the other is enriched throughout; and (e) total, when they are taught together in intended equality. This continuum of integration has been the subject of investigation over the years; however, mainly through smaller action research projects.

## Support for Connected Mathematics and Science Curriculum

While there is a great deal of philosophical literature, there is limited empirical data supporting integrated instruction. Some small-scale investigations into connected mathematics and science curriculum have been conducted, with most having positive results. The limited research may be due to the absence of a common understanding of best practices in integrating and connecting mathematics and science (Berlin & Lee, 2005; Hurley, 2001), which has led to problems when designing, conducting, and interpreting research in this area. Using a mixed methodology to study the benefits of integration, Hurley (2001) found quantitative evidence favoring students' mathematic achievement when mathematics was enhanced within the science class, as well as when mathematics and science teachers planned together collaboratively.

Judson and Sawada (2000) integrated mathematics, specifically statistics, into an eighth-grade science class to examine the impact on mathematics achievement. Science activities were coordinated with the statistics unit several times during a three-week period. Results showed that students in the integrated class had significantly higher achievement on the statistics than those students not involved in the integrated activities. Although results were limited by a lack of controlling for extraneous variables and limited treatment fidelity, this study offers potential for researchers investigating the connection between mathematics and science. Furthermore, Elliott, Oty, McArthur, and Clark (2001) examined critical thinking, problem solving, and attitudes toward mathematics at the undergraduate level through an integrated science and algebra course. While no significant differences in problem-solving skills were found, students in the connected course had larger gains in critical thinking and higher positive attitudes toward mathematics.

More recently, a preliminary meta-analysis of integrated STEM curriculum conducted by Becker and Park (2011) suggested that integrating the STEM subjects has positive effects on student learning. The authors synthesized the existing research on integrative approaches across all grade levels to study the effects on student achievement. While results suggested that an integrative approach had a positive effect on student achievement at the middle school level, effect sizes were mixed on the benefits of integrating mathematics and science, as seven showed a small effect size and two showed a large effect size. While the positive effect sizes are encouraging, only 10 studies were included in the meta-analysis and these employed assorted methodologies, with varying degrees of complexity of mathematics and science.

## Current Reforms for Connected Learning

Further support and acknowledgement of the value of connecting these STEM disciplines comes from the National Science Foundation (NSF) that awarded grants to colleges and universities to partner with one or more school districts to develop mathematics and science partnerships (MSPs), with the goal of raising achievement levels of all students, especially among diverse student populations (National Science Foundation, 2006). Dimitrov (2009) analyzed achievement trends covering three academic years (2003–04, 2004–2005, and 2005–06) of MSPs based on school-level MSP Program's Management Information System and found positive effects on student achievement in mathematics at the middle school level. While the specific level of integration is unknown, results indicate that schools with an MSP focus on mathematics saw an increase in mathematics proficiency at elementary and middle school levels, while the majority of those without an MSP focus experienced an overall decrease in mathematics proficiency. Other findings show that students at lower proficiency levels at the start of the projects experienced increases in proficiency at a higher rate in the schools with a MSP program.

Although the Common Core Standards were not adopted at the time of this study, their recent implementation supports the argument for integrated learning. These Common Core Standards emphasize the integration of mathematics and English language arts into science and other subjects (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010). Common Core recommends teachers should spend class time on mathematical instruction (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010). For instance, one area of mathematics that can be utilized within the science classroom is reasoning using expressions and equations, including solving linear equations.

## A Model for Infusing Mathematics Into Science Curriculum

The need for a useable and succinct framework or model of mathematics and science integration is apparent in both the research base and practice. One such mode was recently developed by The *Mathematics, Science, and Technology Project* (MSTP), a NSF-funded MSP Project. MSTP was a five-year project that involved 10 school districts in New York State (NYS) where students were not meeting state mathematics standards. A key activity of the project was the development of a multidisciplinary instructional model for connecting mathematics with science, technology, and engineering content areas at the middle school level. MSTP introduced the term mathematics *infusion* as an approach to make mathematical interconnections. Similar to enhanced mathematics integration (Hurley, 2001), infusion is where mathematics is taught in a science or technology lesson at critical points leading to a natural fit within the predominant discipline. For example, a mathematical concept such as graphing, taught in a Life Sciences class, where science is the predominant discipline, not mathematics.

As part of MSTP, middle school science and mathematics teachers participated in a training program to create 20 science topics that infused mathematics. The science teachers implemented and taught lessons related to some of the topics during the school year. The students in these classes and students in control classes, who did not participate in the infusion mathematics curricula, completed a pre- and post-content assessment developed by project staff to measure growth in mathematics knowledge over the intervention period. Results found infusion students scored significantly higher on a mathematics content knowledge assessment than their control group counterparts (Hecht, Flugman, Russo, & Almendral, 2009). These results were promising, but further exploration into a cohesive mathematics-infused curriculum is needed to determine its true effectiveness.

## Current Study

The current study was part of the Mathematics Infusion into Science Project (MiSP), a three-year project funded by NSF and conducted by Hofstra University's Center for STEM Research. Utilizing the information obtained from the MSTP, the lesson template was further operationalized and enhanced. This template included a structured outline of the components of mathematics infusion. Similar to MSTP, the goal of MiSP was to improve middle school student mathematics by infusing mathematics into a middle school science curriculum.

The key elements were: Mathematics content is introduced multiple times across six science topics to allow for transference of understanding of concepts; the mathematics component is challenging for students; the mathematics concepts fit naturally within the science lesson and labs; science lessons are inquiry based and of long enough duration to allow for students to engage in hands-on activities using the mathematics concepts; infused mathematics concepts are discussed throughout the lesson and applied during a variety of lab experiences; and the beginning mathematics skills are foundational and built upon for later understanding of more complex mathematics concepts.

In the current study, mathematical elements were grouped into three difficulty levels throughout the lessons that required additional mathematical skills: level 1: graphical representation of data; level 2: examination of slope, visual understanding of linear versus non-linear lines; and level 3: contrast of linear and non-linear lines and developing a linear equation for prediction. In addition, the goal was to increase the cognitive complexity of student learning throughout the study. In addition, three cognitive domains of *knowledge*, *application*, and *reasoning* that were used in the 2007 Trends in International Math and Science Study (TIMSS) assessment framework (Mullis et al., 2005) were also used within the current study. Knowledge items referred to questions that ask students specifically about facts, procedures, and/or concepts; application items assessed students' ability to apply their knowledge to come up with the solution to a problem; and reasoning items required that students think logically about what they know to solve non-routine problems or those that may be complex or multi-step (Mullis et al., 2005).

### Purpose

The present study examined the impact on eighth-grade student learning of mathematics content knowledge where the science teacher taught six mathematics-infused science lessons throughout one academic school year. Each lesson was approximately five class periods of 40–45 minutes in duration. Therefore, there was a total of approximately 30 total class periods of mathematics-infused science lessons. Students in both the infusion and control groups attended similar eighth-grade mathematics courses, but the infusion students were exposed to integrated science lessons, whereas the students in the control groups were not. The following research questions were investigated: (a) Do students who complete mathematics-infused lessons demonstrate gains in the three cognitive domains of knowledge, application, and reasoning of mathematics, as described in the TIMSS framework? (Mullis et al., 2005); (b) Do students who complete mathematics infusion lessons demonstrate gains in the relevant mathematics content that was infused into the science curriculum?; (c) Do students who participate in mathematics-infused science lessons demonstrate greater relevant mathematics content knowledge than students in the control groups in regular science instruction classrooms?; and (d) Is there evidence that mathematics-infused lessons are effective for students whose prior mathematical levels were below the average?

The project is based around the idea that students would be able to learn the mathematics that was infused into the lessons. Therefore, it was hypothesized that infusion students, as compared with students in the control groups, would show significant growth in all three cognitive domains, particularly in application (i.e., students can apply a concept to solve a problem) and reasoning (i.e., students can use the concept to solve a different or more complex problem) areas. Additionally, it was hypothesized that those students who scored below average (as indicated on the state standardized test) would show greater increased mathematical content knowledge compared with similar students who did not participate in the mathematics-infused lessons.

## Method

### Participants

**School requirements.** The principal investigator of the MiSP project recruited administrators from school districts across NYS to take part in the grant and current research. The requirements were that the school had to have at least two science teachers willing to participate and who would be teaching eighth-grade science for two consecutive years. Also the schools had to agree to submit state achievement and demographic data on all eighth-grade students who participated in the study. Eight middle schools agreed to participate in the study and the administrator from these schools agreed to provide the student data requested.

Table 1
*Number of Schools, Teachers, Periods, and Students*

| School | Teacher | Group | Number of Classes |
|---|---|---|---|
| School A | Teacher 1 | Control | 5 |
| | Teacher 2 | Control | 3 |
| | Teacher 3 | Infusion | 4 |
| School B | Teacher 1 | Infusion | 5 |
| | Teacher 2 | Infusion | 5 |
| School C | Teacher 1 | Control | 4 |
| | Teacher 2 | Infusion | 3 |
| School D | Teacher 1 | Control | 4 |
| | Teacher 2 | Control | 4 |
| | Teacher 3 | Infusion | 4 |
| School E | Teacher 1 | Control | 3 |
| | Teacher 2 | Infusion | 3 |
| | Teacher 3 | Infusion | 1 |
| School F | Teacher 1 | Infusion | 2 |
| | Teacher 2 | Control | 1 |
| School G | Teacher 1 | Control | 3 |
| | Teacher 2 | Control | 4 |
| | Teacher 3 | Infusion | 4 |
| School H | Teacher 1 | Infusion | 4 |
| | Teacher 2 | Control | 1 |
| Total | 10 teachers | Infusion | 35 classes |
| | 10 teachers | Control | 32 classes |

**Teacher participants.** Twenty-two teachers from eight schools in NYS were participants in the current study. These schools had between two and four teacher participants who utilized one to five of their classes. The eight teachers were assigned to either the infusion group (taught mathematics-infused science curriculum) or the control group (taught their "business as usual" curriculum). See Table 1 for additional information on each teacher, the group they were in, and the number of classes that were used as part of the study.

To ensure the comparability of the two groups, teacher content knowledge was assessed using a mathematics content knowledge activity and a predetermined rubric to rate teachers' responses. Teachers were presented with two mathematic problems to solve. One involved graphing data, interpreting the graph, and calculating the slope. The second problem involved extrapolation of data and computing the equation of the line. These two problems were based on the types of mathematics problems that would be infused into the lessons. Based on the responses to these two problems, the teacher's level of mathematics proficiency was determined using a rubric. The average ratings of the control and infusion teachers on the mathematics activity were similar. This ensured that both groups of students had teachers with comparable mathematics content knowledge, and that this would not be a factor in student outcome. Not knowing the teachers' pedagogical skills, teachers from within each school were randomly assigned to the infusion or control group.

**Student participants.** There were a total of 784 students in 35 infusion classes and 692 students in 32 control classes, for an overall total of 1,667 students in 67 classes that participated in the project. However, student data could not be collected from some students, due to attrition or non-compliance by the teacher to submit data. Thus, there was a final data set for 1,200 eighth-grade students, which included 641 students within infusion classes and 559 students within control classes.

All eighth-grade students in the infusion classes participated in the mathematics-infused curriculum; however, not all infusion and control students were enrolled in the same science course. Some teachers taught a general intermediate-level science course and others taught an NYS regents-level course. Students enrolled in the regents course take an NYS regents exam at the conclusion of academic year. The regents exams are statewide assessments in core academic areas that are required for a high school diploma. Out of the five required regents exams for graduation, one is in mathematics and one is in science. The control group included 22 general science classes, 7 living environment regents classes, and 3 earth science regents class. The infusion group included 31 general science classes, 3 living environment regents classes, and 1 earth science regents classes.

Demographic information for the students participating in the project was similar for both groups. There were 45.2% female students in the infusion group and 51.7% in the control group. Further, there were similar percentages of ethnicities in both groups. Within the infusion group of students, there were 69% Caucasian, 7% Hispanic, 12% Black, and 12% Asian/Pacific Islander and within the control group there were 74% Caucasian, 14% Hispanic, 4% Black, and 8% Asian/Pacific Islander. Lastly, 29.5% of infusion group students qualified for free/reduced lunch, 4.9% were Limited English Proficient, and 8.8% had an individualized education plan; compared with 24.8%, 3.3%, and 8.3% respectively in the control group. It should be noted that demographic information was unavailable for 249 students from four teachers' classes.

### Procedure

The study used a pre-post quasi-experimental design to examine change in student mathematical content knowledge following participation in the mathematics infusion curriculum. Prior to the start of the program, students in the infusion and students in the control groups were administered an assessment of their knowledge of relevant mathematics that would be addressed in the treatment group. After the period of time determined to implement the intervention (September to May), both groups of students were re-administered a mathematics assessment in an effort to determine whether significant gains in knowledge occurred in the infusion group. NYS mathematics test scores were also collected and analyzed to look for similar patterns in mathematical growth.

**Control "business as usual" curriculum.** Eighth-grade science teachers taught the control classes using the school district science curriculum. NYS does not have a mandated science curriculum for eighth grade, unless in a regents level course; therefore, the lessons taught varied and could include topics in general science, living environment, or earth science curriculum. Example topics from a general science curriculum would be density, thermal conduction, and velocity. Only during the six topics of mathematics infusion did the students in the control groups experience a different curriculum than the infusion students.

**Intervention "science infusion" curriculum.** The mathematics that was infused within the topics focused on the understanding of linear relationships, a concept that students typically find difficult and is essential for mastery of algebra. Further, the study of linear relationships is part of the eighth- and ninth-grade mathematical state standards, and currently a focus of common core mathematic standards, and it naturally fits within a science curriculum, particularly during the conducting and reporting of science labs to help students scaffold their understanding of data analysis.

***Teacher training.*** Both infusion and control teachers attended professional development workshops. The study year's infusion teachers were trained to teach the MiSP topics during a two-week (ten-day) professional development workshop the summer prior to implementation. The workshops were run by project staff, in coordination with the mathematics and science curriculum developers who created the mathematics-infused science topic lessons. One curriculum developer was a professor of biology, who was also a participant during the entire MSTP. The other curriculum developer was an adjunct professor at a local college and a retired NYS school district K-12 science coordinator who had over 20 years of classroom teaching experience at the K-12 and higher education levels. The workshop first provided teachers with instruction about different mathematical concepts (i.e., graphing, slope of a line, and linear equations). Prior to the summer workshop, teachers selected the topics they would teach to fit their curriculum. They selected these based on the individual courses taught (e.g., general eighth-grade science, earth science, or living environment). Thus, the summer workshop also provided teachers with time to practice the science lessons within the topic that they planned to implement.

***Mathematics within the lessons.*** The mathematical content for MiSP focused on linear relationships and also introduced three difficulty levels of mathematics. These were: level 1: graphical representation of data; level 2: examination of slope and visual understanding of linear versus non-linear lines; and level 3: contrast of linear and non-linear lines and developing a linear equation for prediction. For example, at level 1, the students plotted data that were linear or non-linear; at level 2, the students would calculate the unit rate of change for linear data, explaining from a science perspective why the unit rate of change was constant or variable; and at the third level, the students determined the equation of a straight line for linear data.

The mathematics infusion was structured so that students encountered various questions of differing cognitive complexity in the mathematics content throughout the lesson. All topics included science concepts that naturally lent themselves to displaying data graphically and all included hands-on mathematics work, typically occurring during the lab portion of the lesson.

Each topic included seven key sections: (a) an introduction of the lessons and what students would learn about mathematics; (b) a core curricular area: major understandings and related science standards; (c) objectives of each lesson; (d) an overview of what should happen each day; (e) worksheets for students to complete at each of the three mathematics levels (depending upon which format of the topic lesson is being taught); (f) lab experiences during which students could apply mathematics at the different levels; and (g) content-specific unit assessments of student knowledge. In addition, some topic lessons included a discussion of the science background required for teachers, particularly if the curriculum developers believed the approach to the topic might be new to middle school teachers.

For example, a typical (non-infused) middle school lesson on density would have students calculate the density of various materials by measuring the mass and the volume of each sample material. When the particular MiSP lesson was introduced would determine which mathematical concepts was addressed: beginning of the year just level 1, midyear levels 1 and 2, and the end of the year levels 1, 2, and 3. Therefore, the MiSP density lesson that an infusion group would follow has the students plot the mass and volume graphically as a relationship (level 1). Using the graph, students would construct a line of best fit, if necessary, and calculate the slope of the line using two linear data points (level 2). The infused lesson would then require the students to calculate the equation of a line (level 3). Science content-based questions would follow these mathematical tasks, which could be answered from the calculations made at each level. Both control and infusion classes address the same science content standards for each topic (e.g., density); however, they both do not cover all the same middle school mathematics standards within their science class. Traditional middle school science classes may incorporate the level 1 mathematic skills of graphing, but do not typically address level 2 or level 3 mathematic skills.

A total of 29 mathematics-infused science topics were available for teachers to utilize, each designed to be taught at the three difficulty levels of mathematics. That is, for a given science topic, the mathematics could focus on mathematics that was described as level 1, level 2, or level 3. Since the mathematics was typically introduced during the lab section of the lesson, the science content remained the same, but the complexity with which students explored and interpreted the science data varied.

***Implementation of the lesson topics.*** Over the course of the academic year, two science topics at each mathematics level were taught. Therefore, the total exposure for students was six mathematics-infused science topic lessons throughout the year. The first two topic lessons that were taught included mathematics at level 1; the second two included mathematics at levels 1 and 2; and the third two topic lessons included mathematics taught at levels 1, 2, and 3. As mentioned above, level 1 included graphical representation of data, level 2 included an examination of slope and understanding of linear and non-linear lines, and level 3 addressed developing a linear equation for prediction. Since each topic was intended to be approximately five periods long (i.e., five days of 40–45-minute classes), about 30 periods of mathematics-infused lessons were completed by each student (six topics that were five periods, two at each of the three difficulty levels).

Throughout the course of the year 20–24 hours of mathematics-infused lessons were delivered.

Although the science topics may have varied depending on the science curriculum, the difficulty level of mathematics was identical across lessons. It was expected that the infusion teachers would teach two topics per quarter and be finished by the end of the third quarter. Most infusion teachers had at least one topic that was taught during the fourth quarter. This depended on the particular teacher's curriculum and pace. However, all teachers had to be completed with the mathematics-infused science curriculum by May of the fourth quarter, as that was when the post-assessment was administered.

## Measures

**Mathematical content knowledge assessment.** The mathematical content knowledge assessment was developed for this project to assess student understanding of the three difficulty levels of mathematics and assess their ability to answer questions of different cognitive complexity. The assessment questions were developed through an iterative and highly collaborative process that involved review of NYS mathematics and science assessments, examination of mathematics and science textbooks, review and item analyses of assessment questions used during MSTP, and consultation with master teachers (experienced and/or college level teachers) and expert researchers in the areas of mathematics, assessment, psychometrics, and educational psychology. Each question in the item pool was then reviewed by an advisory board and classified according to cognitive domains based on categories (i.e., knowing, applying, and reasoning) used in the TIMSS (Mullis et al., 2005). Items were selected to vary by level of mathematical difficulty and the cognitive complexity domain.

The pre-assessment consisted of 30 questions: 54% of the items were from level 1, 25% from level 2, and 21% from level 3. As noted previously, the mathematics-infused lessons focused on each of the three levels depending upon when it was taught in the school year. Further, the categorization of knowledge, application, and reasoning was used as a second indicator of item differences: 29% of the items categorized as knowledge items, 46% were application items, and the remaining 25% were reasoning items.

At post-testing, additional mathematics content questions were included from level 3 as well as a higher number of application-based items. Thus, the post-assessment consisted of 26% of the items categorized as knowledge items, 53% were application items, and the remaining 21% were reasoning items. Further, 47% of the items were from level 1, 26% were from level 2, and 26% were from level 3. This change was made to help assess student growth, since it was anticipated few students at pre-testing would be able to answer level 3 questions.

**NYS standardized test scores.** Seventh-grade scores from the NYS mathematics standardized assessment, as well as scores from the eighth-grade NYS mathematics and science standardized assessment scores, were collected for each student participating in this study. The Statewide Mathematics Assessment is a combination of multiple-choice and open-ended questions that are scored to produce individual student raw scores. The eighth-grade science assessment, in addition to science content, includes questions that require differing amounts of knowledge of mathematics, which again produce raw scores.

**Treatment integrity.** The integrity of a treatment is measured by the accuracy and consistency with which the elements are implemented as it was planned and described (Gresham, 1989). It is necessary to consistently measure if the teacher is implementing the intervention in the way it was intended. Thus two approaches described below were used to assess the fidelity of the treatment.

***Online implementation feedback survey.*** Throughout MSTP, collecting data immediately following a topic implementation was a highly effective method to track teacher activities. Therefore, this method was utilized again during MiSP. Infusion teachers completed an online feedback survey after each MiSP topic was taught. The survey asked teachers to consider topic timing (e.g., number of days it took to complete the topic lessons), level of mathematics, the success of various aspects of the lesson, teacher's overall lesson rating by class, the most successful and difficult aspects of lesson implementation, and any variations during implementation.

***Classroom observations.*** To further document lesson implementation, a PhD level developmental psychologist conducted classroom observations of all teachers at least once. An observational rubric protocol was developed by adapting the Science Classroom Observation Rubric (SCOR) designed by RMC Research Corporation in collaboration with the LASER leadership and the Washington State Science Coordinators. The SCOR is divided into four categories: (a) learning objectives; (b) developing understanding; (c) sense-making; and (d) classroom culture. This rubric enabled the scorer to focus on skills that can directly be observed in the classroom.

## Results

Paired sample *t*-tests analyses were conducted to assess student differences in mathematics content scores from pre-test to post-tests, for both the infusion and control

Table 2
*Change in Content Knowledge over Time by Group and Mathematics Level*

| | Mean | | Infusion ($n$ = 641) | | | | | Control ($n$ = 559) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SD | Change | $t$ | Eff. Size | Mean | SD | Change | $t$ | Effect Size |
| Pre-level 1 | 48.66 | 17.16 | 20.35 | 23.62 | 1.13 | 53.45 | 18.36 | 8.82 | 9.83 | 0.48 |
| Post-level 1 | 69.01 | 18.72 | | | | 62.27 | 18.30 | | | |
| Pre-level 2 | 54.05 | 18.74 | 10.32 | 11.16 | 0.54 | 56.58 | 19.90 | 3.86 | 3.95 | 0.19 |
| Post-level 2 | 64.36 | 19.64 | | | | 60.44 | 19.94 | | | |
| Pre-level 3 | 17.45 | 18.65 | 19.25 | 17.38 | 0.82 | 19.14 | 19.36 | 13.73 | 12.32 | 0.62 |
| Post-level 3 | 36.70 | 28.23 | | | | 32.87 | 25.31 | | | |

groups. Additionally, independent samples $t$-tests were conducted to compare assessment scores of students in the control group with those in the infusion group. Analyses were conducted at the individual item level, the cognitive domain complexity of the item (i.e., knowledge, application, or reasoning), the difficulty of mathematics level (i.e., levels 1, 2, or 3), as well as the total score level. Finally, analyses of covariance (ANCOVA) were conducted in order to account for any pre-test differences between infusion and control group students.

## Mathematical Content Analysis

**Individual items.** At the individual item level, for the infusion group ($n$ = 641), 29 of the 30 items showed significant increases in percent correct from pre-test to post-tests. One item showed a decrease in percent correct for the infusion group, while the range of increase in percent correct for the remaining items was between .5 percentage points and 47.5 percentage points. The average increase for all items for students in the infusion group was 16.4 percentage points. Students in the control group also showed significant increases from pre-test to post-tests on 19 of the 30 items, for an average of 8.7 percentage points. However, the magnitude of the difference from pre- to post-tests was almost half of the average increase seen in the infusion group.

**Total scores results.** Total scores were computed for each student by summing the number of correct responses and dividing by the maximum number of questions. Table 2 presents pre- and post-mean percentage correct (total) scores on the content knowledge assessment for infusion and control groups as well as by difficulty level and cognitive domain. Both groups demonstrated statistically significant growth. However, based on a paired $t$-tests analysis, the students in the infusion group displayed nearly three times the growth from pre- to post-tests than students in the control groups, yielding a much stronger effect size.

**Analysis of cognitive domain.** As described previously, items were analyzed by the three cognitive domains used in the TIMSS Assessment: knowledge, application, or reasoning (Mullis et al., 2005). Although increases were evident in each area, they were greater for the infusion students and were strongest in the knowledge area. Students in the infusion group exhibited over twice the growth in knowledge items when compared with the students in the control groups, almost twice the growth in application items when compared with students in the control groups, and more than 5.5 times the growth in reasoning items when compared with students in the control groups.

**Analysis of mathematics level.** Student change on the content knowledge questions by levels of mathematics was also analyzed. Again, level 1 involved graphing; level 2 involved slope, and level 3 involved linear equations. Infusion students showed larger effect sizes in all three levels of mathematics when compared with the students in the control groups. Infusion students displayed approximately 2.3 times the growth on level 1 questions than students in the control groups, 2.67 times the growth on level 2 questions than students in the control groups, and 6.0 times better growth on level 3 questions than the students in the control groups. The most significant growth for both groups occurred at level 3. When compared with the control group, students in the infusion group displayed over twice the growth on level 1 items and almost three times the growth on level 2 items.

Separate ANCOVA were used, while controlling for pre-scores, to explore group differences in post- scores for each of the three cognitive areas (Knowledge, Application and Reasoning) as well as across the three levels of math. Results indicate that, after controlling for pre-test differences, infusion students scored significantly better on the post-tests assessment when compared with the control group students (Table 3). Percent differences range from 4.63% (level 3 items) to 8.66% (Knowledge items). The largest effect size was the difference between infusion and students in the control groups for total score.

**NYS standardized test results.** The seventh- and eighth-grade NYS Standardized Mathematics assessment

Table 3

*Analysis of Covariance in Total Scores, Cognitive Domain, and Levels, by Group*

| Item Classification Type | Area/Level | Estimated Marginal Means | | | *F* | Effect Size |
|---|---|---|---|---|---|---|
| | | Control | Infusion | Difference | | |
| All items | Total score | 48.51% | 55.64% | 7.13% | 175.48* | .23 |
| Cognitive type | Knowledge | 65.52% | 74.18% | 8.66% | 49.82* | .08 |
| | Application | 52.43% | 58.96% | 6.53% | 134.00* | .18 |
| | Reasoning | 35.66% | 40.04% | 4.38% | 76.15* | .11 |
| Math level | Level 1 | 61.48% | 69.70% | 8.22% | 78.75* | .12 |
| | Level 2 | 60.04% | 64.72% | 4.68% | 61.50* | .09 |
| | Level 3 | 32.44% | 37.07% | 4.63% | 78.76* | .12 |

* $p < .001$.

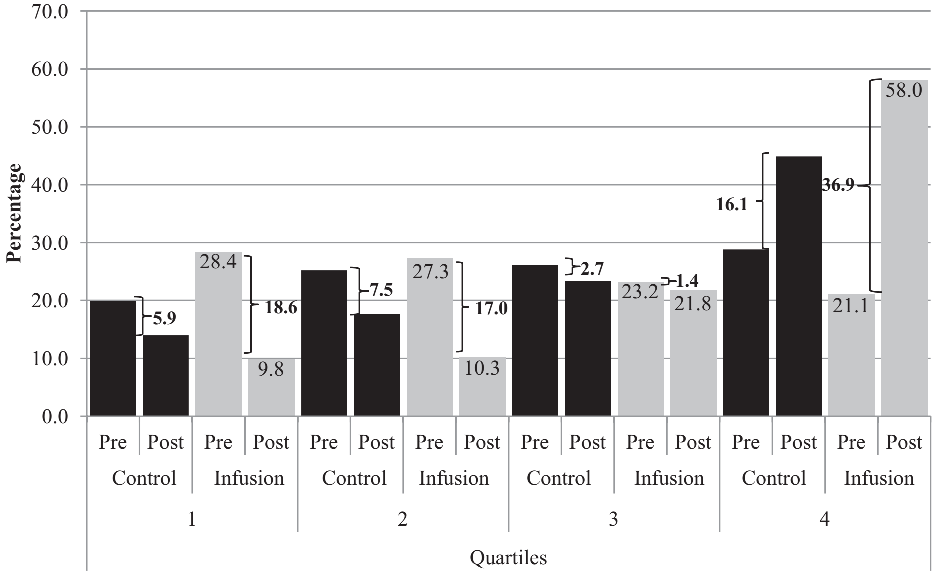

*Figure 1.* Percentage of students falling within quartiles based on total sample pre-score.

scores were examined for infusion and students in the control groups participating in the research study. ANCOVA indicate that, after controlling for initial differences on their seventh-grade mathematics assessment scores, the estimated marginal means for the infusion students ($M = .71$, $SE = .02$) were higher on the eighth-grade mathematics assessment than the control group student scores ($M = .65$, $SE = .02$). Although the main effect of experimental group on eighth-grade mathematics score proficiency was not significant, $F(2, 745) = 3.72$, $p = .05$.

**Student-specific growth.** All students (infusion and control combined) were divided into four equal quartile groups based on their pre-assessment scores. Students who were categorized in the first quartile ($n = 293$; 24.4%) scored between 0% and 30% correct on the pre-test, those in the second quartile ($n = 316$; 26.3%) scored between 31% and 40% correct. Students in the third quartile ($n = 295$; 24.6%) scored between 40% and 50% correct on the pre-test, and students categorized in the fourth quartile ($n = 296$; 24.7%) scored above 50% correct.

As Figure 1 indicates, when the infusion and control groups were examined separately, a larger percentage of infusion students fell into the lower two quartiles at pre-test than students in the control groups. These differences suggest that the infusion group included more students who were struggling with MiSP-related concepts at the beginning of the school year. Infusion group students exhibited greater movement from quartile 1 into higher quartiles and overall more infusion students progressed to quartile 4 than students in the control groups, suggesting greater mastery of the concepts. Infusion group students showed an 18.6% movement out of quartile one compared with 5.9% of students in the control groups. In addition, the percentage of infusion students in the fourth quartile

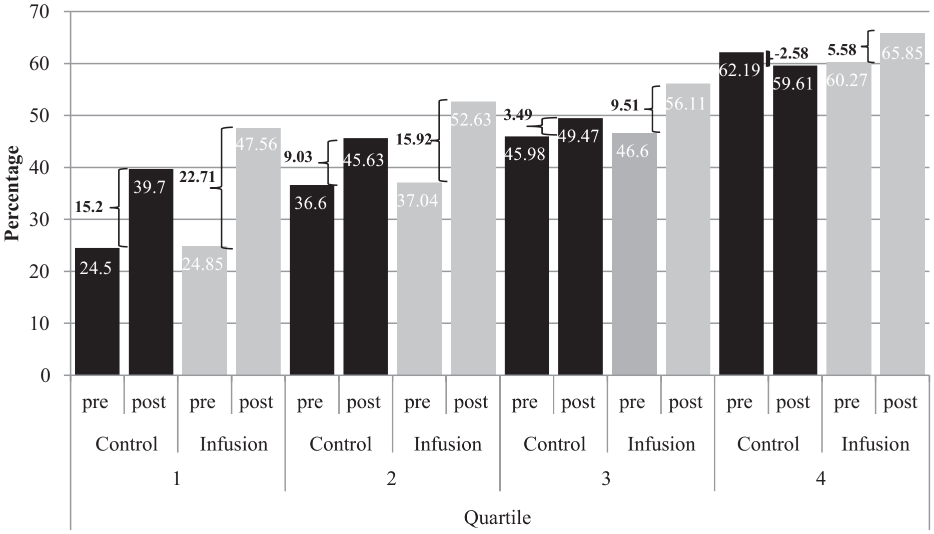

*Figure 2.* Average pre/post scores by pre-assessment quartile category.

increased 36.9%, compared with 16.9% for students in the control groups. Thus, while both control and infusion students showed an increase in the percentage in quartile four from pre to post, there was more than a 20% gain of infusion students progressing to quartile 4 than students in the control groups.

The quartiles used for analysis were again used to examine changes among students within the two groups. This second analysis held the students within each quartile constant (as determined by their pre-scores) and then examined the percentage of correct responses. As Figure 2 indicates, when the infusion and control groups were examined separately, infusion group students showed, on average, greater growth from pre-to post-tests than control group students in all quartiles. While scores increased for both the infusion and control students groups from pre-to post-tests in all categories, infusion students exhibited higher levels of increase than students in the control groups. Infusion students showed a 7.51% difference over students in the control groups in movement out of the first quartile and 8.16% difference in scores for infusion students over students in the control groups in movement into the fourth quartile.

**Treatment integrity implementation feedback survey.** Ninety percent of the infusion teachers completed an online survey each week. Teachers used a 5-point Likert type scale ranging from 1 (not at all successful), 3 (moderately successful) and 5 (very successful) with choice 2 and 4 falling numerically in between in the scale, to rate their success in completing key tasks of MiSP infusion lessons (infusing mathematics into science, enhancing the mathematics taught, making mathematics more meaningful to students) and average scores were calculated for lessons at each difficulty level. Average scores were highest for level 1 ($M = 3.475$; $SD = .906$), but teachers reported they were overall generally successful at each task, regardless of the level of mathematics that was introduced ($M$=3.4075; $SD = .906$).

Teachers were also asked to write a narrative about what was most and least successful about implementing the lesson. Responses tended to vary by level, but most teachers reported the most successful elements were the hands-on components of the lessons and that learning mathematics helped students understand the science. When teachers were asked what was most difficult about implementing the mathematics-infused lessons at level 1, teachers reported difficulties related to implementing a new lesson (e.g., time, directions). Teachers working with levels 1 and 2 reported graphing issues and teachers working with levels 2 and 3 reported slope related issues (e.g., unable to find slope even with formula, difficulty memorizing formula).

**Treatment integrity classroom observations.** An experienced person in psychometrics observed teachers using the SCOR observation tool. These observations found that most lessons were implemented with high fidelity. All teachers used the lesson plan materials as intended, which included using the materials and worksheets provided. Despite high treatment integrity, there was variability in the method of delivery and introduction of additional materials. For example, some teachers would have students read instructions as a class while others had students read independently. Teachers showed great variation in the subcategories of explaining learning objectives, developing understanding, sense-making, and classroom culture, with scores ranging from 0, indicating little or no evidence of each subcategory, to 6, indicating exemplary demonstration of each subcategory. The total scores on the SCOR observation tool ranged from 6 to 21 on a 24-point scale across the observations. Overall, high levels of treatment integrity indicate significant legitimacy to the positive results of this study.

## Discussion

The purpose of the study was to explore the use of infusing mathematics into an eighth-grade middle school student science curriculum. The study compared students exposed with the mathematics-infused science curriculum to students who were not exposed. Pre-post differences in student mathematical content knowledge and skill were examined on three different difficulty levels and three levels of cognitive domains, as well as on the NYS mathematics standardized assessment. Results of this study support the hypothesis that mathematics-infused science at the eighth-grade level significantly impacts student mathematics content knowledge. When compared with students who did not experience the intervention, students in the infusion group showed statistically significant increases on the overall mathematical content assessment, as well as in subcategories of the assessment divided by area of cognitive domain complexity and difficulty of mathematics.

Most notably, student-reasoning skills increased for those in the infusion group above and beyond what would be expected during a typical school year. Infusion students had more practice and were better prepared on a variety of mathematical concepts and scored significantly higher on the NYS eighth-grade mathematics assessment than students who did not receive mathematics-infused instruction. This finding is encouraging, as it implies that students who learn mathematics in a variety of contexts are better able to retain mathematical concepts and perform better on assessments than students who learn mathematics as a stand-alone content.

Analysis of the quartile data indicated there was greatest improvement for students who scored in the lowest quartiles on the pretest. As indicated in the results, students that entered the eighth-grade with a lower level of mathematics ability improved significantly as a result of their involvement in MiSP. At the time of post-assessment, more students in the infusion group increased their proficiency when compared with students who were not exposed to mathematics-infused instruction. As mentioned, this indicates that contextualized mathematics in science has an added value for students who are low performers in mathematics. The results of this study provide a compelling argument for the mathematics-infused science model. Contextualized instruction appears to have a significant impact on learning, as indicated by a statistically significant increase in scores.

## Limitations

While the current study was conducted as rigorously as possible, there were limitations to its implementation. First, while fidelity of implementation was monitored, there was variability in the way in which the mathematics-infused lessons were administered, as evidenced by responses on the online surveys and teacher observations. In addition, some teachers explained that they were introducing the mathematical concepts for the first time, while other teachers reported that students had already been exposed to the mathematical concepts by the mathematics teacher. Teaching the mathematical concepts for the first time in a science class may have presented a barrier for some teachers, as they were not equipped to introduce the concepts but reinforce them within the science context.

Teacher effectiveness was another limitation of the current research. As prior research has shown, measures of teacher preparation and certification have a strong relationship to student achievement, especially in reading and mathematics (Darling-Hammond, 2000). The effectiveness of teachers, including the years of experience, teaching style, certification, training, etc., of both infusion and control teachers may have had an impact on student engagement and learning of the mathematics. While an attempt in this research was made to document and control for the level of teacher's mathematics content knowledge, little else was done to document or define other aspects of teacher quality. It is possible that these variables may have had an impact on student achievement of the mathematics.

In addition, the mathematics classes that students were enrolled in were not taken into account in the current study. Students could have been in an NYS regents-level algebra class or general eighth-grade mathematics class, which focuses on pre-algebra concepts. Since this information was not gathered data it was not possible to take into account students learning in higher level mathematics classes. This could have confounded the data for some students.

## Future Research

The current study makes a great contribution to research on the value of a connected mathematics and science curriculum. While the main goal of the current study was to assess mathematics content growth in eighth-grade students, future research should address science content growth as well. In essence, the goal of our project was to increase mathematics learning, but research should be expanded to focus on the type of science that could benefit most from mathematics infusion. As Becker and Park (2011) found, connected curriculum is beneficial to students, but the effect on each discipline may vary, especially by grade level and connectedness of the curriculum. Therefore, it is imperative this avenue be explored.

Teacher effectiveness should also be of note in future investigations. This may include considerations of years of experience, content knowledge in mathematics and science, and the ability to engage students. All may be factors that impact student outcome. Future research should focus on the impact of the teacher and their ability to incorporate integrated lessons.

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## Author's Note

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