DEVELOPMENT OF A MULTIDISCIPLINARY MIDDLE SCHOOL MATHEMATICS INFUSION MODEL

Maria Russo and Deborah Hecht
Center for Advanced Study in Education, Graduate Center of The City University of New York

M. David Burghardt and Michael Hacker
Hofstra University

Laura Saxman
Center for Advanced Study in Education, Graduate Center of The City University of New York

The National Science Foundation (NSF) funded project *Mathematics, Science, and Technology Partnership (MSTP)* developed a multidisciplinary instructional model for connecting mathematics to science, technology and engineering content areas at the middle school level. Specifically, the model infused mathematics into middle school curriculum through the alignment of science, technology, engineering, and mathematics (STEM) curriculum, creating a mathematics infused curriculum planning template for teachers, and the implementation of connected STEM professional development workshops in middle schools. Through data collected from teachers, administrators, and faculty members involved in these activities, it was found that all involved were satisfied with connected curriculum, STEM teachers were able to successfully increase their own mathematics pedagogy and content knowledge, and students were able to grasp mathematical concepts when they were applied in science, technology, or engineering content areas.

Numerous documents have reported that American students are failing to achieve grade level mathematical standards. For instance, according to *Foundations for Success,* the 2008 Report of the National Mathematics Advisory Panel, American students' mathematics achievement is "at a mediocre level" compared with that of their peers and this decline in achievement tends to begin when students reach late middle school (U.S. Department of Education, 2008). There are numerous strategies that schools and teachers can utilize to counteract student failure in mathematics, including changes in the curriculum, modification in teaching methods, or an increase in mathematics teacher preparation.

• **Maria Russo,** Center for Advanced Study in Education, Graduate Center of The City University of New York, 365 Fifth Avenue, Suite 3300, New York, NY 10016. E-mail: MRusso1@gc.cuny

Middle Grades Research Journal, Volume 6(2), 2011, pp. 113–128
ISSN 1937-0814

The National Council of Teachers of Mathematics (NCTM) contends one way students can increase their mathematical competency is for teachers to connect mathematics to situations from science, social science, and commerce (National Council of Teachers of Mathematics, 2002). Preliminary research suggests that mathematical connections such as these can help students relate mathematics topics to their daily lives, enhance their understanding of mathematics, and help them see mathematics as a useful and interesting subject (Reed, 1995). Moreover, Czerniak, Weber, Sandmann, and Ahem (1999) suggest that connecting mathematics and science may not only enable students to develop a common core of knowledge, but possibly become more interested and motivated in their science and mathematics classes. This connected learning also appeals to educators, as it mirrors the real world, links subject areas, and fosters collaboration and networking among teachers (Kaufman, 1995).

Of all of the reform recommendations being made by NCTM, making mathematical connections to other areas is among the more difficult, yet most important to achieve, especially at the middle school level where students are beginning to appreciate the power of mathematics (Reed, 1995). It is possible that making connections between mathematics, science, technology, and engineering (STEM) might be the answer American schools have been looking for to raise achievement in mathematics. Nonetheless, most middle schools do not actively make connections between the STEM areas on a regular basis.

Mathematics Infusion Defined

Connecting STEM curriculum in the schools has taken on a plethora of different meanings in both the education and STEM literature. There have been numerous terminologies used to describe these connections, such as interconnected, integrated, infused, connected, etc. These discrepancies cause difficulty not only for the understanding of what each term implies, but also in synthesizing past research results. Therefore, in 1992 the National Science Foundation (NSF) School Science and Mathematics Association (SSMA) held the Wingspread Conference in an attempt to develop a clear succinct definition of mathematics and science integration, as well as a rationale for integrated science and mathematics teaching and learning. In an attempt to clarify these definitions, SSMA assigned this task to working groups of science, mathematics and education faculty members, teachers, and other related professionals (Berlin & White, 1992). While definitions were proposed for mathematics and science integration, no full consensus could be reached. This lack of a definition was a topic of interest for numerous researches and educators in the years since the Wingspread Conference.

For instance, Hurley (2001) systematically reviewed the math-science integration literature and classified five different levels of math-science integration. These include: sequenced, parallel, partial, enhanced, and total integration, which are from least to greatest level of integration. Sequenced integration takes place when science and mathematics are planned and taught sequentially, with one preceding the other. Parallel integration occurs when science and mathematics are planned and taught simultaneously through parallel concepts. Science and mathematics can also be taught partially together and partially as separate disciplines in the same classes, entitled partial integration. Enhanced integration occurs when either science or mathematics is the major discipline of instruction, with the other discipline apparent throughout the instruction. Lastly, total integration is where science and mathematics are taught together in intended equality. Defining integration through these five forms not only summarizes the past research conducted, but also provides a reference point for further research to build upon.

Research Context for Mathematics Infusion

A lack of a universal description of mathematics and science integration has led to problems when designing, conducting, or interpreting research in this area (Hurley, 2001). Even though there has been a great deal of support for mathematics connections to other content areas in the literature, the lack of empirical research grounded in theory is apparent (Berlin & Lee, 2005). However, when Hurley (2001) used mixed methodology of student achievement data, qualitative data on the multiple forms of integration, and historical evidence of publishing patterns from across the twentieth century, it was found that there is some quantitative evidence favoring integration. More specifically, it was found that student mathematics achievement was greater when it was taught in sequence with science, as well as when mathematics and science teachers planned collaboratively together.

Ross and Hogaboam-Gray (1998) attempted to tackle the lack of mathematics integration evidence by comparing one school that integrated ninth grade mathematics, science, and technology courses into a single MST program, to a similar school where all three subjects were taught separately. The integrated school had blocked mathematics, science, and technology for three 85-minute periods each day. Teachers collaboratively arranged topics, so that all three subjects worked in sequence as a coherent whole, with an emphasis on a common framework for problem solving. Researchers found the integrated students were more likely to maintain a mastery orientation to learning and were engaged in more productive task talk and less off-task than students in the control (segregated) courses.

Additional research attempted to examine mathematics integration by comparing lessons that taught STEM in an integrated way, to the same lessons that did not use any integration. For instance, Merrill (2001) studied an integrative approach to teaching and learning at the high school level, by comparing a technology class that was taught using connected science and mathematics lessons, to comparison classes that received an identical content lesson without the integrated and hands-on approach. Results found that there was no significant difference between the experimental and comparison group on posttests, although both groups experienced similar gains. Even though no significant increase over the comparison class was evidenced, it should be noted that the treatment period duration in this study was only 2 weeks and all implementation was done by the technology teacher without working cooperatively with mathematics or science teachers.

Similar to Merrill (2001), Judson and Sawada (2000) conducted an action research study examining student outcomes when an eighth grade science class was integrated with mathematics (statistics). In the experimental statistics classroom, the science teacher co-taught with the statistics teacher and coordinated the science activities with the statistics unit (a repeated sequence of problem presentation, strategy determination, and data collection) several times during a 3-week period. It was found that the achievement of the students in the experimental group was significantly higher than that achieved by students not involved in the integrated activities. However, results were limited by a lack of controlling for extraneous variables, little to no treatment fidelity, and a noted lack of real change in teacher pedagogy.

As is evidenced by prior research, connected STEM instruction is an enduring concept, as there have been diverse rationales, curriculums, and research illustrating interconnected teaching and learning throughout the years. Despite these advances, the field has yet to establish a clear understanding of the benefits of interconnected instruction, as well as the preeminent means to develop, implement, assess, and research interconnected STEM teaching and learning.

Mathematics, Science, and Technology Partnership (MSTP)

Unfortunately, despite these compelling rationales and the influence of the NCTM, mathematics and science are still often taught in an unconnected way in schools (Watanabe & Huntley, 1998). One project that has focused its efforts on connecting Science, Technology, Engineering and Mathematics in order to improve mathematics teaching and learning in middle schools is the *Mathematics, Science, and Technology Partnership (MSTP)*. MSTP was a 5-year National Science Foundation (NSF) funded Mathematics and Science Partnership Project conducted by the Hofstra University Center for Technological Literacy (CTL). MSTP was situated in 10 districts in New York State where students have failed to meet state standards in mathematics. A key activity of the project was the development of a multidisciplinary instructional model for connecting mathematics into Science, Technology and Engineering (STE) content areas at the middle school level.

Moving away from the idea of mathematics integration, MSTP introduced the term 'mathematics infusion' as an approach to make mathematics interconnections between STE. Through infusion, mathematics is introduced into the STE lessons at critical points, so it naturally fits with the material that is taught in the STE content area and interconnections are made between the disciplines. Therefore, the MSTP project did not attempt to combine STEM into a curricular whole, but allowed each subject to maintain its own unique perspective, with mathematics infused throughout. It is based upon the idea that as science and technology teachers infuse their lessons with mathematics, their students will increase in both their conceptual knowledge of and fluency in mathematics.

In order to understand the MSTP mathematics infusion model, the essential components and data to support these components will be presented. More specifically, a curriculum revision and alignment process in middle school mathematics and science, the use of a *curriculum template* that guides teachers in selecting content, pedagogy, and assessments for lessons, collaborative professional development initiative for school-based and higher education faculty, and an examination of mathematics infused lessons through the use of a math-infusion rubric and lesson study. Through the exploration of these components, data will be presented that demonstrates the effectiveness of this model for increasing student mathematics knowledge, as well as teacher content and pedagogical knowledge.

METHOD

Curriculum Revision and Alignment

The curriculum revision and alignment process took place throughout the entirety of the 5-year MSTP Project. There were two types of curriculum alignment. In terms of mathematics specific alignment, MSTP districts aligned their mathematics curriculum with New York State (NYS) Mathematics Standards, so mathematics instructions met the NYS Mathematics standards for that grade level. Further, each middle school stressed the three basic understandings of the NYS mathematics standards in their mathematics classrooms. These understandings are: Procedural fluency so that "the skill in carrying out procedures flexibly, accurately, efficiently and appropriately"; conceptual understanding so "students use conceptual understanding of mathematics when they identify and apply principals, know and apply facts and definitions, and compare and contrast related concepts"; and problem solving or that a "concept or procedure in itself is not useful in problem solving unless one recognizes when and where to use it as well as when and where it does not apply" (New York State Board of Regents, 2005).

Attention was also paid to the timing of mathematics coverage in other disciplines, which lead to the second method of alignment. At the outset of MSTP, middle school faculty and administrators worked on aligning mathematics Grades 5–8 curriculum to determine which mathematical concepts connect to specific portions of the science and technology curricula content. For example, in many schools, curriculum was mapped to middle school standards and a scope and sequence was developed that aligned middle school mathematics, science, and technology topics by grade level. A scope and sequence is essentially a plan for instruction that broadly describes the curriculum at various grade levels with a focus on identification of unifying concepts.

If a specific scope and sequence was not planned, school based faculty outlined the general sequence of when mathematics, science, and technology concepts are introduced within a grade, so that students will have both the needed skills/knowledge and maximum exposure of the concepts. This type of alignment occurred in the majority of the MSTP districts. Topics were rearranged to coincide with one another and similar ideas are taught, while remaining separate subjects. In addition, when aligning curriculum, it was stressed to teachers that the languages and pedagogy used in the classrooms should be similar across mathematics and science classes. Further, numerous schools revised their curriculum to adopt National Science Foundation (NSF) endorsed curriculum, such as Math in Context (MIC) and Connected Mathematics (CMP).

Lesson Planning Template

Another vital element of the MSTP mathematics infusion model was the development of a lesson planning template for mathematics infused science and technology lessons, as well as for enhanced mathematics lessons. The lesson planning template was developed collaboratively and various sources were tapped, including the expertise of university faculty members, and related literature, STEM teachers, and curriculum experts.

These lesson planning templates guide teachers in selecting content, pedagogy and assessments for mathematics infusion and/or mathematics enhancement, with a focus on inquiry based learning and instruction. There are several key mathematics infusion areas that have been integrated into the use of the template. For instance, teachers must identify one or two major mathematics and science content topics, along with the related process and performance standards that they will be covering in their lesson. Hence, teachers will consider links in what they are teaching to the standards in greater detail. A large focus of the lesson template is the instructional planning of the lesson, where teachers are to indicate the lesson progression in detail. As mathematics infusion into science is one of the most important features, teachers must explicitly mention how they were able to infuse mathematics into the science or technology content of the lesson.

Another necessary component of the lesson plan is embedded assessment. Each lesson should include some measure of student learning in mathematics and science or technology, either in the shape of formative or summative assessment. A checklist of assessment methods is included in the template to help teachers consider which evaluative techniques would be most appropriate for their respective lesson designs. Lastly, the template includes a reflection section where teachers contemplate the strengths and limitations of each lesson. This is particularly important in assisting teachers with the development and revision process, considering how to better address student learning with their respective populations, and supporting future teachers who might decide to implement the lesson design.

A/B Workshops

Professional development is essential, as many studies reveal a startling lack of subject matter knowledge even with mathematics and science teachers (Adams, 1998; Babbitt & Van Vactor, 1993; Ball, 1991). Teacher preparation is therefore a fundamental prerequisite to infusion of mathematics into school practice. However, teacher preparation must consist of more than general content knowledge. Teachers must be provided with the content knowledge and pedagogical skills needed to implement mathematics teaching in constructivist ways, as well as instruction in finding ways to make the mathematics material meaningful within different academic content areas.

The MSTP project addressed teacher professional development in three ways. Throughout the project yearly multidistrict workshops were implemented to address the pedagogical and content knowledge needs of involved STEM teachers. Further, an important feature of MSTP was that each school district was able to shape how it provides professional development and how it builds an MSTP community. This was realized through school-based teams (called Collaborative School Support Teams or CSST) in each district to support mathematics infusion and mathematics enhancement. The CSST included a mathematics teacher, a science teacher, a technology teacher, a school social worker or guidance counselor, a school administrator, and a university faculty member. The CSST members were responsive to the diverse needs of their specific district. Over the course of the project, the professional development culminated with a within school learning community approach called the "A/B Workshops". These workshops engaged MST teachers with CSST guidance to develop and implement mathematics infusion and mathematics enrichment in the classroom. It should be noted that the CSST teams were trained over 3 days in how to successfully implement these workshops with teachers in their district.

The MSTP district based A/B workshops provided STE teachers with an opportunity to work with mathematics teachers and university faculty in a structured way, as they designed, implemented, and revised mathematics infused science and technology lessons and enhanced mathematics lessons. This professional development model is unique because most often professional development involves teachers attending classes or workshops to learn about new content, pedagogy, and/or advancements in the field of education that they must then work to link to their own practice. The experience, however engaging, is often disconnected from what occurs in teachers' classrooms, with new practices being difficult to implement in their own classrooms (Martin-Kniep, 2004). The A/B workshop model sought to eliminate this disconnect through its unique elements, which allowed teachers to meet in professional STEM learning communities to develop their content knowledge and pedagogy as they designed their own lessons.

These workshops took place on two separate days, first the A workshop and then the B workshop. The focal point of the A workshop was on lesson plan development, where teachers worked collaboratively in mixed discipline learning communities to create a 2- to 3-day mathematics infused lesson on the MSTP template. Other middle school science, mathematics, and technology teachers from their district, as well as the university faculty member of the CSST team provided feedback and assistance. In addition to developing lessons, teachers created pre/post student assessments and a scoring rubric to assess student learning of lesson objectives.

Teachers were expected to spend the 2 weeks after the conclusion of workshop A implementing their lessons in their respective classrooms during the regular school day. Teachers recorded their reflections about the lesson and its degree of success immediately following implementation. In addition, teachers scored all student work and selected three samples representing varied levels of student performance (good, passable, and poor) that would allow for a more in-depth analysis of student understanding. Finally, after implementing their lesson, teachers met again for the second phase, the B workshops. During the B workshop teachers again met in mixed discipline STEM learning communities to reflect and undergo peer review in order to revise and rework their lesson in a way that would optimize student learning. Teachers examined the collected student work samples, discussed pedagogical issues, and ultimately revised their lessons based on their own experiences and input from their colleagues.

Following each workshop, all participants were asked to provide feedback about the experience of developing and using the lessons, as well as to report on learning and changes they observed in their students. Interviews were also conducted with a sample of teachers to ascertain their own personal growth through the process. To further assess teacher growth, a rubric was used to quantify teacher development and understanding of the model, as reflected in lesson plans developed during the yearlong initiative.

Lesson Study

All of the MSTP lesson plans created during the 2006-2007 yearlong A/B workshops were collected to be used for the MSTP lesson study. All identifiers were deleted from the lesson plans before they were submitted for review and rating. Each lesson was given a unique identification number, which denoted the district, date of lesson and teacher. Through the use of a MSTP created rubric, teacher growth, development and understanding of the model as reflected in the developed lessons was assessed and quantified. Although separate rubrics were developed for use with mathematics and for science/technology lessons, the general content of both is similar. Each was used to examine if the lesson included all essential components of the template, as well as the degree of mathematics infusion, expected student understanding, and extent of real world applications. Each area was assessed on a 0- to 5-point scale, with 0 indicating the element was not present to 5 indicating the element was met.

Common areas for both the mathematics and science/technology rubrics include if the lesson conforms to the required format, if instructional planning procedures are explicit enough to allow for replication, and if the mathematics/science content is accurate. There were also areas assessed that were directly related to mathematics infusion, such as, if students are provided with opportunities to apply important mathematical concepts, if mathematics and science concepts are applied in an inquiry-based way, and if the lesson improves student conceptual understanding of mathematics and mathematical procedural fluency.

All lessons were reviewed and rated by an independent consultant. The consultant had an extensive background in education, having taught science, mathematics and technology. In addition, the consultant had experience in professional development, teacher education, and lesson planning. Prior to rating the lesson plans, she underwent training to ensure rater consistency and reliability.

RESULTS AND DISCUSSION

Curriculum Revision Process and Lesson Template

The change in MSTP project schools was seen by both teachers and their administrators. Participating teachers reported that mathematics across the curriculum made “a tremendous difference” and indicated that students see “concrete connections between what they’re learning and what they do.” Principals anecdotally noted consistent infusion of mathematics into science and technology and engagement of students in higher order thinking was apparent. Further, the MSTP project was able to assist numerous schools to adopt National Science Foundation (NSF) endorsed curriculum, such as Math in Context (MIC) and Connected Math (CMP). In seven of the 10 Project schools, teachers had integrated exemplary MIC and CMP mathematics materials into instruction. One district had even adopted MIC and has been supported by MIC developers and publishers.

To add to this, teachers felt that the template was an integral part of the mathematics infusion process. Across all workshops, 92.5% teachers stated ‘yes’, they were able to use the MSTP lesson template to create a successful lesson that included enhanced mathematics and/or that infused mathematics into science or technology. One teacher explained, “The form [template] allowed for the thought process in how to infuse the mathematics concepts into science and technology.” Another teacher noted, “Yes, explaining the steps we took to create the lesson helped us to break down the topics and see connections in science and math.” Teachers who indicated they could not usefully apply the template explained it was difficult to find appropriate grade-level mathematics to infuse, they had trouble using the computer document version of the template, or they did not like the process of planning every element of a lesson.

A/B Workshop Model

The A-B workshops were held over 3 years of the project, changing in small ways throughout to meet different teachers or districts needs, but maintaining the core components and concepts. During the first year of workshops (2006-2007) each district held six A-B workshop cycles in their home district, for a total of 54 workshops completed. During the second year (2007-2008) seven districts choose to participate, the majority holding four workshops each, for a total of 24 total workshops. The last year of the workshops (2008-2009) five nonproject districts were recruited to take part in the MSTP workshops, and successfully held four workshops each, for a total of 20 workshops.

During the A-B workshops (across 3 years) MSTP was successful in holding almost 100 workshops in 15 different school districts. A total of over 580 hours of professional development was delivered to STEM teachers in participating districts. Further, almost 300 teachers were involved and developed over 1,000 lessons during the 3-year time period.

The preponderance of participants (over 95% of all teachers) during the first 2 years of A-B workshops found the workshop to be useful or positive. Throughout the first 2 years there were only eight teachers who rated the experience as not at all useful to their teaching practices. These teachers indicated that the A/B process was rushed, they desired additional opportunities to work with teachers from other disciplines, or they disliked the paperwork involved. Even though the question changed slightly during the third year, these results were replicated, as over 95% of teachers indicated the A/B workshop was a very positive or positive experience, with not one teacher rating the workshops to be negative or very negative. These are highly impressive response rates, considering the number of teachers involved in the project over time and the amount of engagement and work required from teachers who participated in the A/B professional development model. One science teacher spoke about how the A/B workshops influenced her and her colleagues, explaining, "It's [A/B workshops] more of an awakening for teachers than students. It provided us with an opportunity to plan together as a group. It was nice because the teachers who participated wanted to do it."

What is equally striking is that teachers were very likely to use the lesson they developed in the workshops again at a later date. The majority of the participants during the A/B workshops would definitely use this lesson again (64%), with 29% indicated they probably would and 6% reported they would maybe use the lesson again. Less than 1% indicated they would not use their development lesson again, indicating that the majority of participants felt the A-B workshops were useful to their practice as teachers.

Further, as Table 1 indicates, teachers were generally satisfied in the lesson development process of the A/B workshops. Teachers saw these workshops as extremely constructive in creating high quality lessons that aided students in their understanding of the material. Over 82% of teachers (2006-2007) indicated they were successful or very successful in writing lessons that helped students develop a deeper understanding of the mathematical content. With over 93% noting that they were successful or very successful in collaborating with teachers in order to write lessons during the workshop. Teachers also strongly supported writing lessons based on the work during the A/B workshops, indicating the workshops were an important facilitator of the lesson writing process.

To future capture the utility of the A-B workshop components, the 2007-2008 survey specifically asked if various activities were helpful during the A and B workshops. Data

TABLE 1
Teacher Ratings of Lesson Plan Development Based on Last 2006-2007 Survey Results

		Not at all Successful		*Moderately Successful*		*Very Successful*
	n	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Writing lessons that help students develop a deeper understanding of math.	106	0%	0%	17.9%	50%	32.1%
Collaborating with teachers in order to write lessons.	105	1%	1%	4.8%	31.4%	61.9%
Writing lessons based upon work at A/B workshops.	106	0%	1.9%	18.9%	49.1%	30.2%

TABLE 2
Number and Percent of Teachers' (2007-2008) Who Responded That the Following Activities Were Helpful During the A and B Workshop

		Across A Workshops		
	N	*Not Helpful*	*Moderately Helpful*	*Very Helpful*
Creating lesson plan drafts on MSTP template	116	8%	36%	56%
Creating pre/post assessments drafts	117	5%	35%	60%
Creating scoring rubric drafts	110	11%	47%	42%
Peer collaboration and review	119	2%	18%	79%
Support provided by faculty members	116	3%	14%	83%
		Across All B Workshops		
Examining sample student work	108	5%	35%	60%
Peer collaboration and review	111	3%	23%	74%
Receiving warm and cool feedback	107	4%	34%	63%
Revising lesson plans	106	3%	31%	66%
Revising pre/post assessment measures	108	4%	47%	49%
Revising your rubrics	101	10%	53%	38%
Reflecting on implemented lesson	110	6%	26%	68%
Support provided by Faculty members	111	5%	19%	77%

shown in Table 2 are responses from teacher in all districts during all workshops. The majority of teachers throughout the workshops found the support provided by faculty members (83%) and from peer collaboration and review (79%) to be very helpful during the A workshop. Teachers also felt creating lesson plan drafts on the MSTP template and creating pre/post assessments drafts during the workshop were useful, with approximately 90% of teachers indicating these activities were moderately to very helpful.

As previously discussed, teachers were allotted time during each B workshop to revise their lesson based upon collected student work, their own reflections, and the comments they received from their peers and faculty to aide mathematics infusion. Approximately 83% of teachers (2006-2007) indicated they used their collected assessment data to revise their lesson, student activities, or assessment tools. One teacher explained, "Results of student work drove my decision to rewrite pre/post assessments and lab packets." The majority of teachers reported that examining student work was helpful in deciphering what the students did not understand and on which areas they needed to spend additional time. During the 2007-2008 B workshop, as can be seen in Table 2, all activities were reported to be at least moderately helpful, with most being very helpful. For example, the majority of teachers throughout the workshops found the support provided by faculty members (77%), reflecting on implemented lesson (68%), and revising lesson plans (66%) to be very helpful.

Over time teachers successfully created multidisciplinary learning communities that resulted in greater collaboration and connections among mathematics, science and technology subject areas. Survey results (2006-2007) show that 90% of teachers agreed or strongly agreed that workshops met their needs for collaboration with other teachers. One teacher noted, "The more time I spent collaborating with my fellow teachers the better my lessons and the greater the impact on my students." Additionally, 86% of teachers agreed or strongly agreed that meeting collaboratively during the workshops helped them to develop new math, science, or technology teaching techniques. Results were similar for the 2007-2008 workshops, with 97% of teachers indicating peer collaboration and review was moderately to very helpful.

Furthermore, through the year long 2006-2007 A/B workshops teachers reported great confidence in both their ability to teach their developed mathematics infused lessons, as well as their ability to use these lessons to increase student understanding. For example, approximately 73% of teachers reported they were confident to highly confident in infusing mathematics into science and technology, as per their lesson developed in the A/B workshops. As one science teacher explained, "MSTP workshops exposed me to our schools mathematics curriculum and allowed me to teach concepts in creative ways." Teachers also reported that the A/B workshops allowed them to improve on their own ability to teach math, as 80% of teachers indicated that they were confident to very confident that the A/B workshops allowed them to develop their mathematics pedagogy. Teachers also indicated that they were confident to very confident that they were able to provide students with real world solutions for using mathematics (93%), as well as emphasize connections between mathematics and science/technology (90%).

Obviously, an important outcome of the A/B model was for students to develop a deeper conceptual understanding of the mathematics concepts, in both mathematics lessons and STE lessons. Across all workshops, teachers generally reported that over 95% of students developed a deeper understanding of the topics covered in the lessons. Several teachers based their response upon students improved performance on the post test measure. One teacher during the 2006-2007 workshop stated, "Through my post observations, I was able to immediately see students understanding and how their understanding grew before to after the lesson." Other teachers explained that students developed the deeper understanding from making real life connections or applications that were included in their lesson.

Teachers were also asked to indicate what percentage of their students scored at 'good', 'passable' and 'poor' on the teacher administered post assessment (preferably using their rubric) during 2006-2007 and 2007-2008 workshops. The greatest percentage of teachers reported that their students' scored at the good or passable range, indicating that students were benefiting from the developed les-

TABLE 3
Teacher Rating of the Percentage of Students' Who Scored at "Good," "Passable," and 'Poor'

	Project Year					
	4 (2006-2007)			*5 (2007-2008)*		
Teacher Rating	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
Good	321	53%	24.28	34	64%	24.41
Passable	320	33%	19.08	34	27%	19.19
Poor	317	14%	10.71	34	9%	8.02

TABLE 4
Percentage of Students' Who Learned the Mathematics and Science/Technology Concepts and Tasks, Based on 2008-2009 Teacher Survey Results

	n	*0%*	*1%-24%*	*25%-49%*	*50%-75%*	*75%-90%*	*100%*	*N/A*
Mathematics concepts	134	0%	0%	3%	12%	76%	8%	1%
Science concepts	130	0%	1%	4%	10%	49%	15%	21%
Technology Concepts	124	0%	1%	2%	3%	38%	8%	48%

sons. On average across all the months, teachers rated that 59% of their students scored in the "good" range on their post assessment. Moreover, around 30% of teachers indicated students scored in the "passable" range, while only 12% of the teachers reported their students fell into the "poor" range. Please see Table 3 below for more information. Regardless of this, these results are promising, as at least 86% of total students were passing or above according to teacher administered post assessments.

Student understanding was assessed slightly differently during the 2008-2009 school year. This year, teachers were asked to indicated the percentage of their students that learned the mathematics, science, and technology concepts and tasks that were presented in their lesson on a scale from 0% (did not learn concepts) to 100% (learned all of the concepts). As can be seen in Table 4, the majority of teachers indicated that their students learned 75 to 90% of the concepts that were covered in their lessons. Moreover, teachers indicate they anticipated their students should be able to score higher on the state assessments, due to their own participation in the A/B workshops and increased ability to enhance or infuse mathematics throughout the curriculum. For example, during 2006-2007 almost 80% of teachers were confident to very confident that their lessons would create change so students would score higher on mathematics assessments. Many teachers indicated qualitatively that their lessons and involvement in the A/B workshops would help their students on state and in classroom mathematics tests. As one teacher explained, "as it is said 'more effective educators produce more effective students'", while others simply indicated "better scores" or "improved state test scores."

Although the majority of teacher comments were positive, a few had critiques about the workshops. These teachers indicated that the A/B process was hurried, they desired additional opportunities to work with teachers from other disciplines, and they would like additional instruction in how to teacher constructivist mathematics. For instance, one teacher explained, "The time to fully develop, plan and implement a lesson is rushed." However, the majority of negative comments were given during the earliest months, or workshops, when the process was still in its developmental phase. Furthermore, limitations in the lessons were noted, among them an insufficient amount of infused mathematics, a grade-level math-science mismatch, and minimal use of reform-based mathematics pedagogy. It was hypothesized that these limitations were related to deficiencies in teachers' content knowledge and difficulties involved in developing exemplary curriculum materials.

In summary, it was found that teachers experienced growth in both their understanding of the concept of mathematics infusion into science at the middle school level and their valuing of mathematics within the science classroom. Teachers were able to use the developed MSTP template to create enhanced math, or infused science/technology lessons and be part of STEM learning communities. Additionally, the majority of teachers believed these lessons helped students develop a deeper understanding of mathematics and/or science concepts.

Lesson Study

Over 150 teachers were able to develop and implement mathematics enhanced and mathematics infused science or technology lessons. After the completion of these workshops, there were over 373 mathematics lessons, 266 science lessons, and 62 technology lessons, for a total of 701 lessons developed. In order to assess teacher growth, a rubric was used to quantify teacher development in understanding of the model through the lesson plans created during the yearlong initiative.

Exploratory analyses were performed on the science lesson plan data to examine the pattern of teacher growth and development in lesson planning over time. A scale was created from the initial set of items that sought to reflect lesson quality with an emphasis on inquiry based methods, mathematics infusion and student understanding. Items were selected for the scale on the basis of variability and higher order lesson planning constructs. While general lesson planning skills such as replicability are certainly important with respect to creating a useful and coherent lesson, they are not necessarily indicative of a plan to engage the learner in an active way that promotes understanding. Therefore, items included in the scale are predominantly those that assess lesson content targeted to enhance student understanding and competencies. See Table 5 for further information.

Items were averaged together to create an overall Mathematics Infusion score for each lesson plan. As indicated in Table 6, 14 out of 20 teachers showed percentage increases from their first lesson plan to their last lesson plan. The average change across all teachers was an increase of 24% from their first lesson plan to their last. Half of the teachers had beginning scores of 3.7 or above, so a ceiling exists with respect to the magnitude of increase possible. For the initial ratings, only two teachers had scores below two. Therefore, their initial lesson plans had contained very little that would engage the learner and drive mathematical competency and understanding within a science lesson. Both teachers showed significant gains with final scores of 3.8 and 4.7 and percentage increases of 174% and 193% respectively.

Overall, there was a progressive improvement and understanding of the mathematics infusion pedagogy. The majority of teachers (70%) increased in their lesson plan quality from the first workshop sequence and rating to the last. Examination of this change in lesson plans over time indicated increased understanding and application of the mathematics infusion model. Going forward, more fine-grained analyses on the lesson plan study can be done. For example, growth patterns between other data points can be examined and district based analyses can be performed. For future measurement of lesson plan quality, it may be worthwhile to revise and/or delete some of the items. For instance, an item that was not selected to be included in the Mathematics

TABLE 5
Items for Lesson Plan Rating Score

Number	*Item*	*Scale Range**
1	To what extent does the mathematics content indicated in the lesson plan have potential to lead to greater understanding of science/technology content?	0-5
2	To what extent does the lesson plan provide students with opportunities to apply important mathematical concepts that are typically difficult for students at this level?	0-5
3	To what extent is the mathematics concept applied in an inquiry-based way?	0-5
4	To what extent is the science concept applied in an inquiry-based way?	0-5
5	To what extent does the lesson plan provide students with opportunities to improve their conceptual understanding of math?	0-5
6	To what extent does the lesson plan provide students with opportunities to improve mathematical procedural fluency?	0-5
7	Is the mathematics content accurate?	0-5
8	To what extent does the lesson seem realistic for the time allotted?	0-5
9	To what extent are mathematics assessments appropriate to the content taught?	0-5

Note: 0 = the element was not present; 5= element was met.

TABLE 6
Mathematics Infusion Scale Scores by Science Teacher and Month

Teacher of Lesson	*Month of Workshop*	*Mathematics Infusion Scale Score (0-5)*	*Percentage Change From First to Last Lesson Plan/Workshop*
1	October	5.0000	-42.00%
	December	2.9000	
2	November	2.3000	+100%
	December	1.3000	
	February	.7000	
	May	4.6000	
3	November	1.4000	+174.42%
	December	4.2000	
	February	3.8000	
	April	3.8000	
4	November	1.6000	+193.75%
	December	4.7000	
	February	4.7000	
5	October	3.2000	+3.12%
	November	3.6000	
	December	3.7000	
	February	4.5000	
	April	4.2000	
	May	3.3000	
6	November	4.2000	+11.90%
	February	4.7000	
7	November	3.7000	+16.22%
	May	4.3000	

(Table continues on next page)

TABLE 6
(Continued)

Teacher of Lesson	*Month of Workshop*	*Mathematics Infusion Scale Score (0-5)*	*Percentage Change From First to Last Lesson Plan/Workshop*
8	October	3.2000	+15.63%
	November	4.6000	
	April	3.7000	
9	October	4.3000	+13.95%
	November	3.5000	
	December	3.4000	
	February	4.9000	
10	November	4.3000	+9.30%
	December	4.7000	
	February	4.7000	
11	October	4.6000	-2.17%
	November	2.3000	
	December	2.5000	
	February	4.5000	
12	October	4.1000	+7.31%
	November	4.6000	
	December	4.7000	
	February	4.4000	
13	October	3.9000	+18.75%
	December	2.5000	
	February	4.8000	
14	December	3.4000	-5.89%
	February	3.2000	
15	October	4.1000	-17.07%
	November	.7000	
	December	.8000	
	February	1.0000	
	April	.9000	
	May	3.4000	
16	November	2.8000	+60.71%
	December	4.2000	
	April	2.2000	
	May	4.5000	
17	October	4.3000	
	November	2.3000	+4.65%
	December	4.5000	
	February	3.6000	
	April	4.0000	
	May	4.5000	
18	November	4.6000	+6.52%
	December	3.6000	
	February	4.9000	
19	October	4.4000	-18.18%
	December	3.6000	
20	October	4.0000	-70.00%
	November	4.5000	
	December	4.7000	
	February	2.9000	
	April	4.5000	
	May	1.2000	

Infusion Scale ("To what extent does the plan conform to the required format?") due to lack of variability could be revised to more accurately assess the use of the lesson template. It may be that the rater interpreted the item to mean whether all sections of the lesson template were completed, not the quality of completion.

Results from this study suggest that the A/B workshop model promotes a professional learning community climate at the school even after the workshop is over. Teachers reported that the frequency of a variety of activities increased from the first A/B workshop in the cycle to the last. What is especially interesting to note is that the teachers reported changes occurring at their actual schools beyond the scope of the workshop. In addition, the quality of the lessons produced by the teachers improved over time. Therefore, there was tangible evidence of improved lesson plan quality as a result of the four cycles of A/B workshops.

CONCLUSION

A "mathematics infusion" approach, or mathematics content taught in science or technology classes, was the vision of the MSTP Project. There are numerous obstacles to mathematics infusion into STE in the middle school, including teacher inexperience (lack of mathematical content knowledge and pedagogy skills), attitudes ("why should I be teaching mathematics in my science or technology class?"), the need for appropriate and accessible curricular materials, effective assessment methods (that demonstrate how infusion affects student learning in math, science, and/or technology), and how to deliver professional development to teachers.

Regardless of these issues, the MSTP Project was able to incorporate a well-developed model of mathematics infusion in middle schools, which was able to increase both teacher pedagogical and content area knowledge and enable teachers to create lessons that infused mathematics. In turn, these lessons were able to increase student learning and performance. This MSTP mathematics infusion model, as evidenced by qualitative administrative support, professional development teacher feedback, and results of the lesson study, was able to accomplish the goals of connecting mathematics and science skills in order to increase student mathematical conceptual understanding. The model provides guidance for both professional development activities and classroom implementation and teachers in science and technology report a value added to their content area from enhanced mathematics performance by middle schools students. This is consistent with Czerniak et al. (1999), where it was suggested that meaningful student learning occurs when new knowledge and skills are embedded in context and students make connections among ideas.

The implications of this approach are great. Not only is it critical to find ways to enhance mathematical understanding and competencies among students, but it is also important that students develop proficiency in using the mathematical concepts that are required in order to master many scientific concepts introduced. Although standards within individual STEM areas suggest the value of cross-discipline connections, this work provides guidance for implementation and indicates the feasibly for widespread mathematics infusion.

REFERENCES

Adams, T. L. (1998). Prospective elementary teachers' mathematics subject matter knowledge: The real number system. *Action in Teacher Education, 20*(2), 35-48.

Babbitt, B. C., & Van Vactor, I. C. (1993). A case study of mathematics learning disability in a prospective teacher. *Focus on Learning Problems in Mathematics, 15*(1), 17-71.

Ball, D. L. (1991). Research on teaching mathematics: Making subject matter knowledge part of the equation. In J. Brophy (Ed.), *Advances in research on teaching: Teachers' subject matter knowledge and classroom instruction* (Vol. 2, p. 1-48). Greenwich, CT: JAI Press.

Berlin, D. F., & Lee, H. (2005). Integrating science and mathematics education: Historical analysis. *School Science & Mathematics, 105*(1), 15-24.

Berlin, D. F., & White, A.L. (1992). NSF/SSMA *Wingspread Conference: A network for integrated science and mathematics teaching and learning conference plenary papers* (Topics for Teachers Series No. 7). Columbus, OH: School Science and Mathematics Association.

Czerniak, C. M., Weber, W. B., Jr., Sandmann, A., & Ahem, J. (1999). A literature review of science and mathematics integration*.* *School Science & Mathematics, 99*(8), 421-430.

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science & Mathematics, 101*(5), 259-271.

Judson, E., & Sawada, D. (2000). Examining the effects of a reformed Junior High School science class on students' math achievement. *School Science & Mathematics, 100*(8), 419-426.

Kaufman, A. (1995). *What research says about integrated curriculum.* Research, Evaluation and Planning Board, Board of Cooperative Educational Services of Nassau County.

Martin-Kniep, G. O. (2004) *Developing learning communities through teacher expertise*. Thousand Oaks, CA, Corwin Press

Merrill, C. (2001). Integrated technology, mathematics, and science education: A quasi-experiment. *Journal of Industrial Teacher Education*, *38*(3), 45-61.

MSTP Project. (2003). Retrieved from http://hofstra.edu/MSTP August 13, 2005.

National Council of Teachers of Mathematics. Overview of Principles and Standards for School Mathematics. (n.d.) Retrieved from http://www.nctm.org/standards/overview.htm

New York State Board of Regents. (2005). *New York State Learning Standard for Mathematics; Prekindergarten - Grade 12.* Retrieved from http://www.p12.nysed.gov/ciai/mst/math/documents/mathcore. pdf

Reed, M. K. (1995). Making mathematical connections in middle school. ERIC Identifier: ED380309. Columbus, OH: ERIC *Clearinghouse for Science Mathematics and Environmental Education*.

Ross, J. A., & Hogaboam-Gray, A. (1998). Integrating mathematics, science, and technology: effects on students. *International Journal of Science Education, 20*(9), 1119-1135.

U.S. Department of Education. (2008). Foundations for Success: Report of the National Mathematics Advisory Panel. *ED.gov*. Retrieved from http://www.ed.gov/about/bdscomm/list/mathpanel/index.html

Watanabe, T., & Huntley, M. A. (1998). Connecting mathematics and science in undergraduate teacher education programs: Faculty voices from the Maryland collaborative for teacher preparation. *School Science and Mathematics, 98*(l), 19-25.