Infusing Mathematics into Science, Technology, and Engineering Classes: Lessons Learned from Middle School Teachers and Students

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Introduction

As numerous state and national reports document, students, particularly those at the middle school level, are failing to achieve the mathematical competencies needed to compete in a rapidly changing technological society. The National Council of Teachers of Mathematics (NCTM) contends one way students can increase their competency in math is to connect math to situations from science, social science, and commerce (National Council of Teachers of Mathematics, 2002). Of all of the reform recommendations being made by NCTM, making mathematical connections is among the more difficult, yet, most important to achieve. Mathematical connections can help students relate math topics to their daily lives, understand math better and help them see math as a useful and interesting subject (Reed, 1995). Moreover, Czerniak, Weber, Sandmann, and Ahem (1999) suggest that connecting math and science enables students to develop a common core of knowledge, but even possibly become more interested and motivated in their science and math classes. Research shows that connected learning also appeals to educators, because it mirrors the real world, links subject areas, and fosters collaboration and networking among teachers (Kaufman, 1995).

Despite these compelling rationales and the influence of the NCTM Connections Standard that suggests that students should have opportunities to recognize and apply mathematics in contexts outside of mathematics (National Council of Teachers of Mathematics, 1989), math and science are still often taught in an unconnected way in schools (Watanabe & Huntley, 1998). Obstacles to infusion include teacher inexperience, attitudes, and beliefs. Furthermore, many studies reveal a startling lack of subject matter knowledge even in teachers within mathematics and science (Adams, 1998; Babbitt & Van Vactor, 1993; Ball, 1991). Teacher preparation therefore, is one 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 skills needed to implement math teaching in constructivist ways, as well as instruction in finding ways to make the math material meaningful within different academic content areas.

The five-year NSF funded project, *Mathematics across the Middle School MST Curriculum - the Mathematics Science Technology Partnership (MSTP)* Project, has focused its efforts on infusing mathematics into other content areas and improving teaching and learning in middle school mathematics in New York. A key activity of the project has been the development of a multidisciplinary instructional model for infusing mathematics into science, technology, and engineering (STE) at the middle school level. This model was developed to connect the disciplines and improve student learning in the process. The math infusion model was developed through an iterative process that involved examination of existing models and literature, consultation with teachers and higher education faculty, reviews by experts, and field based work in which math infusion approaches were discussed, tried-out and evaluated by teachers and students. The model was developed through the integration of the following components: 1) middle school curriculum revision and alignment in MSTP schools; 2) use of a “curriculum template” that guides teachers in selecting content, pedagogy and assessments for math-infusion; 3) collaborative professional development activities for school-based and higher education faculty (A/B Workshops); and 4) an impact study of the efficacy of the math infusion into STE model. These four components and evidence for their use are the focus of this paper in relation to infusion of math into STE.

MSTP Math Infusion Model

Math Infusion defined

A problem arises when trying to define math integration or infusion, mainly due to a lack of consensus upon a definition for both terms. In a review of the math-science integration literature, Hurley (2001) found five forms of integration, and defined each type from the least to the greatest level of integration: sequenced, parallel, partial, enhanced, and total 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. Partial integration is found where science and mathematics are taught partially together and partially as separate disciplines in the same classes. Enhanced integration happens when either science or mathematics is the major discipline of instruction, with the other discipline evident throughout the instruction. Lastly, total integration is where science and mathematics are taught together in intended equality.

The MSTP project used the term ‘math infusion’, which is similar to what Hurley (2001) would call ‘enhanced integration’. It can be defined as mathematics content taught in science or technology classes, where the science or technology is the major discipline of instruction. This should be considered contextualized infusion, as math is delivered within connected science or technology lessons or activities. It is based upon the idea that as science and technology teachers infuse their lessons with math; their students will increase both their conceptual knowledge and fluency in mathematics. The results of the MSTP Project indicate that student math content knowledge improves significantly, particularly for the students academically performing initially in the bottom half of the class.

Curriculum Revision and Alignment

The first process toward the creation of the math infusion model was a curriculum revision and alignment process. Middle school faculty and administrators have worked on aligning mathematics curriculum with state standards and assessments and determining which mathematical concepts connect to specific portions of the science and technology curricula. 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. This way, mathematics was taught at times that was helpful for students to understand the science.

Lesson Planning Template

Another vital element of the math infusion model was the development of a lesson template, for math infused science and technology lessons, math infused technology/engineering lessons, and enhanced mathematics lessons. These templates guide teachers in selecting content, pedagogy and assessments for math infusion and/or math enhancement. There are several key math infusion areas that have been integrated into the template. For instance, teachers must identify one or two major math and STE content topics, along with the related process and performance standards they will be covering in their lesson. Hence, teachers will consider the links from what they are teaching to the standards. A large focus of the lesson template is devoted to the instructional planning of the lesson, where teachers are to indicate the lesson progression in detail. In math infusion into STE lessons teachers must explicitly indicate how they were able to infuse math into the science 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 STE. 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 to Support Lesson Plan Development and Implementation

An important feature of MSTP is that each school district can shape how it provides professional development and how it builds an MSTP community. This characteristic was realized through the establishment of seven-person Collaborative School Support Teams (CSST) in each district. CSST members included a teacher of mathematics, science, and technology, the middle school administrator, and a guidance counselor or social worker. Two university disciplinary faculty members were also involved to support each team. The CSST members are responsive to the diverse needs of their specific district and were instrumental in conducting the MSTP professional development activity, the “A/B workshops”, in each project district.

The district based A/B workshops allowed teachers to meet in professional STEM learning communities to develop their STEM content knowledge and pedagogy. The workshops provided science, technology, and mathematics teachers with an opportunity to work with the CSST team in a structured way, as each teacher designed, implemented, reviewed and revised math infused science lessons. These workshops took place in two separate parts (A workshop and then 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 and refine lessons. During the A workshop, teachers used the MSTP developed lesson templates to guide development of 2 to 3 day math infused lessons. Feedback and assistance was provided by other middle school science, math, and technology teachers from their district, as well as the university faculty member of the CSST team. The goal was to build more explicit and inquiry-based mathematics into the existing STE curriculum that was, in most instances, also inquiry-based. In addition to developing lessons, teachers created pre and post student assessments, along with a scoring rubric to assess student learning of lesson objectives.

Teachers were expected to spend the two 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 lessons and its degree of success immediately following the 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 this time teachers 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 and CSST members.

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.

Impact studies of the math infusion model

In addition to development of the professional development model (A/B workshops), the MSTP Project has undertaken two impact studies of the feasibility of math infusion and student outcomes when math infused lessons are taught within STE middle school classrooms. This impact work explored math infusion from the perspective of teachers and students. Building upon teacher experiences during the A/B workshops, six science teachers, with assistance from project staff and expert STEM consultants, developed longer (20 days) of math infused lessons during the 2007-08 school year. Building upon lessons learned during the 2007-08 study, a more rigorous evaluation was undertaken in the fall of 2008 with eight science teachers developing 20 days of math infused science lessons. Further, in the fall of 2008, 15 middle school technology teachers implemented a math infused technology/engineering unit (Bedroom Design, also 20 days) that was previously developed and piloted by technology teachers the prior year.

The majority of teachers involved in this initiative were from the MSTP Project high needs districts in New York State. The science and technology/engineering teachers met for a week and a half of professional development workshops during the summer prior to the academic school year when the lessons would be implemented. Present at these workshops were science and technology teachers, project staff, higher education faculty (specializing in STEM), and middle school administrators. The goals of this week long training were for each science teacher to develop 20 days of math infused science lessons, the technology teachers to revise the 20-day bedroom design unit, and for each teacher to increase their conceptual and pedagogical understanding of mathematics. In order to infuse the math properly, teachers received math content knowledge and various teaching strategy instruction. This instruction allowed the teachers to increase their own knowledge of the math topics, as well as inform them about various methods they could use to infuse these topics into their own disciplines.

Both studies focused on student change in mathematics content knowledge and attitudes following participation in math infusion lessons. Each STE infusion teacher had a comparison teacher (another STE teacher from the same middle school) who did not teacher the math infusion lessons, but instead taught the typical curriculum for that school. Student mathematics achievement data and attitudinal data were compared pre and post participation in the infusion lessons, as well as with data from students in comparison classes. The primary research questions for both studies were: (1) how did infusion student mathematics performance and attitudes change after participating in math infused science lessons? and (2) how did the performance of the infusion and comparison students compare? It was hypothesized that it would be feasible to teach math infused lessons when they were of adequate duration and intensity (at least 20 days), students would demonstrate increased understanding of the mathematics content taught, and students would have increased positive affect about mathematics.

In the first study, mathematics achievement was assessed through a combination of 19 open ended and multiple choice questions items drawn from validated and reliable New York State (NYS) 7^{th} and 8^{th} grade assessments, in which content was relevant to the mathematics taught in the math infused lessons. In the second science study, mathematics achievement was assessed in a similar manner, through 14 open-ended and multiple questions adapted from NYS math assessments. The technology students were assessed with a similar assessment, comprised of 16 questions pulled from NYS assessments and developed by expert math consultant to the project. The attitudinal survey for both years was built from a review of existing math and science attitudinal research and upon three years of prior work with teachers to address key mis-understandings or mis-conceptions of students. The survey included a five-point Likert scale, in which students responded to statements about their attitudes toward math, connection between math and science and how they perceived themselves as math students.

Teacher feedback data concerning the lessons, process and perceived impact on student were collected weekly and in post-study focus groups. More specifically, teachers' were surveyed on a weekly basis about the type and amount of math that was infused in their lessons, their and student reactions during the week of lessons, and any difficulties or challenges they faced. Focus groups focused more on formative feedback about the experience of teaching math infused lessons in science. Data were gathered on student reactions, difficulty with teaching the material, student reactions to the experience, student outcomes in terms of math and science performance, and their interest in using these lessons again.

Results and Discussion

Curriculum revision process and lesson template

Change in MSTP project schools were reported by both teachers and their administrators. Participating teachers indicated that math across the curriculum made "a tremendous difference" and indicated that students see "concrete connections between what they're learning and what they do." Principals noted consistent infusion of mathematics into science and engagement of students in higher order thinking was apparent. To add to this, teachers felt that the template was an integral part of the math 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 math and/or that infused math into science. One teacher explained, "The form [template] allowed for the thought process in how to infuse the math 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."

A/B workshop model

In 2006-2007 each of districts held six A/B Professional Development workshops and a total of over 300 math infusion science lessons were collected during this time. During 2007-2008, seven of these districts continued with the A-B workshop model, creating over 100 additional lessons. A total of over 200 teachers participated in these workshops. It was found that over time teachers successfully created multidisciplinary learning communities that resulted in greater collaboration and connections among STEM areas. Over 93% of teachers noted that they were successful or very successful in collaborating with teachers to write lessons, while 86% of teachers agreed or strongly agreed that meeting collaboratively helped in the development of new math and science teaching techniques. Several teachers noted the A/B model guaranteed they had time to do tasks that are often not valued, such as reflecting on their own practice and sharing with colleagues. Lesson plans showed progressive improvement and understanding of the math 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 math infusion model.

Teachers also saw these workshops as extremely useful in creating high quality lessons they could use again in years to come. For instance, over 85% of the teachers reported they would use the MSTP lessons developed during the A/B workshops again. Moreover, over 90% of the teachers reported that they used the template to develop math-infused lessons which resulted in students having a deeper conceptual understanding of math. However, 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 math pedagogy. It was hypothesized that these limitations were related to deficiencies in teachers' content knowledge and difficulties involved in developing exemplary curriculum materials. The second phase of research, the impact study, sought to eliminate this disconnect.

Impact study of the efficacy of the math infusion into STE model

The impact of math infusion into science and math infusion into technology were examined separately. Although a somewhat similar model was used (i.e., the science or technology was the primary subject while math was added into the curriculum), the specific approach varied slightly. In science, new lessons were developed by teachers that fit within their existing curriculum. Thus, each science teacher in the project implemented different math infusion lessons. Attempts were made to keep the type of math constant, but the science varied. In technology, a single lesson, Bedroom design, was taught by all teachers. In both subjects, the study involved examining the feasibility, as well as student impact in math content knowledge and attitudes toward math.

<u>Math Infusion in Science:</u> Student data, feedback surveys and focus groups from the impact study phase indicated that science teachers were confident in their ability to teach the math; lessons were doable within science units; and students were open to learning math within science. These results

were seen even with only minimal direct exposure for students to math instruction (between four and eight hours of math instruction embedded within 20 days). Data from the 2007-08 study revealed an improvement in student content knowledge from pre-infusion lessons to post. In the fall of 2008, a more rigorous replication study was undertaken that confirmed the finding of the initial 2007 study that math infusion is doable in middle school classes. The replication study involved a much more robust and complex intervention, incorporated enhanced assessments, and involved eight science teachers and over 500 students in the experimental group and nearly 400 in the control group. The math was more advanced and the science lessons were more inquiry based and complex. Once again math infusion into science was still found to be feasible and student growth was evident.

A quasi-experimental approach was used for both studies. Students were administered two assessments before and after the 20 days of math infused lessons. The first assessment examined content knowledge related to the types of math introduced in the lesson. Questions were selected from the NY state seventh and eighth grade math assessment, and included both multiple choice questions and open ended questions that required students to show their work. The open ended questions were scored on a four point rubric that ranged from a score of 0 (indicating no evidence of mastery of the math being presented) to two (indicating students showed all their work and solved the problem correctly.) Because the open ended questions were intended to assess deeper conceptual understanding of the math, separate content knowledge scales were computed for the multiple choice and open-ended questions and transformed to a percentage correct. Therefore, scores on both scales range from 0 to 100. In addition, students answered an attitude survey developed for this work. The Likert-type questions asked students about the relevance of math and their interest in math. Although the assessments were revised somewhat after the 2007-2008 study, the findings were similar. Given that both the infusion and comparison students received instruction on the science topics at the same time, it was expected that both groups would demonstrate some improvement. In actuality, the results revealed the infusion students demonstrated greater mathematical knowledge when compared to the comparison students.

Student Math Content Knowledge: The data were examined in several ways. When students scores from the 2007-08 data was divided into quartiles based upon pre-test performance and their means compared with their post performance, three out of four quartiles showed improvement on both the multiple choice and open-ended items. Performance change was most dramatic for students who scored in lower quartiles. See Table 1 and 2 below for information regarding both the multiple choice and the open-ended scales for the science infusion students.

Table 1. Multiple choice scale quartiles for infusion students (2007-08).

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Pre Means	19.89	42.9	69.03	93.19
Post Means	40.29	55.17	69.79	82.7

Table 2. Open-ended scale quartiles for infusion students (2007-08).

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Pre Means	7.55	24.66	39.97	63.99
Post Means	25.38	35.36	44.57	59.35

Paired t-tests were also used to compare infusion and comparison students' math content knowledge on the 2007-2008 data. Infusion students showed significant improvement on both scales from the pre-test to the post-test. While the comparison students also showed some improvement, it was less dramatic than the infusion group. See table 3 below for full detail of the results.

Table 3. Infusion vs. comparison students (2007-08).

Group	N	MC scale Pre-test (sd)	MC scale Post-test (sd)	Rubric Pre-test(sd)	Rubric Post-test (sd)
Infusion	520	56.82 (25.31)	62.50 (25.10)**	33.19 (22.16)**	40.68 (22.64)
Comparison	367	52.75 (24.70)	54.39 (25.14)	30.83 (21.10)	32.95 (19.27)*

*paired t-test differences: p<.05; **paired t-test differences: p<.001

The fall 2008 replication indicated similar findings to the first study. Although the math in the second impact study was more advanced than in study one, and the science lessons were more inquiry based and complex, math infusion into science was still found to be feasible. To assess student content knowledge an assessment was developed that reflected the mathematics in the science lessons, which included 14 items (multiple choice and open-ended) adapted from the NYS assessment). At the individual item level, six out of eight multiple choice items and three of the seven open-ended items showed significant increases from pre-test to post-test for the infusion group. For the comparison group, three out of eight multiple choice items and two out of seven open-ended items showed significant increases from pre-test to post-test.

Once again separate summed scores were computed for the multiple choice and open ended questions and each was transformed to a 100 point scale. For students in the infusion group, multiple choice total scores increased from 60.99 to 67.26, or 6.27 percentage points from pre-test to post-test. While, on the open-ended questions, infusion students increased from 37.62 to 45.65, a total increase of 8.03 percentage points from pre-test to post-test. Comparison students did not have a significant increase in scores from pre-test to post-test on either the multiple choice or the open-ended questions. Further, an Analysis of Covariance (ANCOVA) was used to statistically controlled for initial math achievement differences between groups by using. The ANCOVA revealed significant differences between infusion and comparison students at post-test after controlling for the differences in their pre-test scores for both types of questions.

A composite score was also computed that included both the multiple-choice and open-ended questions. A paired sample t-test revealed a statistically significant average increase of 7.16 percentage points for the infusion students. Although analysis of data from the Comparison were also significant; students increase was only 3.02 percentage points. Further, an ANCOVA revealed that infusion students scored significantly higher than the comparison students by a margin of 8.16 percentage points. Results can be seen in Table 4.

Table 4. Comparison of total scores of science students by group (fall 2009).

	Infusion Classes (N = 454)	Comparison Classes (N= 319)	Infusion v. Comparison

	Infusion Classes (N = 454)			Comparison Classes (N= 319)			Infusion v. Comparison		
	Mean Pre	Mean Post	Mean Difference	Mean Pre	Mean Post	Mean Difference	Inf.	Comp	Diff.
Total 11	49.30%	56.46%	7.16%**	45.27%	48.29%	3.02%**	56.46%	48.30	8.16%**

Note: *p < .05, **p < .01

Data from this replication study were further analyzed to explore possible mediating variables. An exploratory series of ANCOVA's were performed, controlling not only for initial, pre scores on the math assessment, but also controlling contextual variables such as school and teacher quality. Meaningful mediating factors were not found. For example, teacher quality was assessed through classroom observation and was included in data analysis. After controlling for teacher quality as well as pre-test scores, students who received the intervention still showed significant improvements in their content knowledge as opposed to comparison group students who showed little improvement.

In summary, infusion students scored Significantly higher at post-test than pre-test on individual items, items grouped by type, as well as on the total assessment. In addition, infusion students scored significantly higher than their comparison group counterparts on both measures of content knowledge. The intervention appeared to have a positive impact on student knowledge of math as it relates to science content.

Student Attitudes: Infusion students' during 2007-08 not only demonstrated increased knowledge of math concepts, but also improved affect toward math. Statistically significant ($p < .05$) pre-post t-test differences were found for the infusion students on eight of the 17 attitudinal items. For all items, the post scores reflected more positive attitudes. Students more strongly agreed on the post administration that: understanding math makes learning science easier; doing math during science is enjoyable; doing well in science is important; it is important to be able to solve math problems to do well in science; the best way to learn math is to have teachers show you how to solve the problems; math and science careers are interesting; math is not boring; math is important in everyday life; and complex math problems are solvable. Statistically significant differences between the infusion and comparison students' post scores were found on four items dealing with enjoyment of math during science, interest in math, math not being a waste of time, and math not being boring. In all cases, the infusion students expressed more positive attitudes than the comparison students.

Student attitudinal data from the fall 2008 study were also examined to determine if middle school students changed their attitudes toward mathematics after being part of mathematics infusion related curriculum. A paired-samples t-test revealed infusion student found math less interesting and less relevant in their lives, but they were more confident after participating in the math infusion lessons. There were no significant differences in attitudes for the comparison students. Yet, when the two groups were compared on only the post assessment, using an independent samples t-test, infusion students felt that math was more important and they felt more confident in their mathematical skills at post-test after controlling for their pre-test scores.

Classroom impact: Feedback from science teachers that were involved with both studies indicates that the math infusion model was easy to implement and added to student learning of both math and science. As one teacher reported, "The beginning unit skills [science unit skills] you do math because science skills blend with math skills, for example, measuring objects. Later, however, for example with proportion, if students do this skill wrong, they could use different math to get the answer." Another teacher noted, "Before I was uncomfortable teaching the single lessons. But now, I feel more comfortable because the math was more consistently integrated." Teachers indicated that through more time spent on teaching the math, students not only conceptually understood the math, but it also added to their science abilities. As one teacher stated, "They [students] understand more science because they have a deeper mathematical understanding." It was further found that school context was a meaningful variable when considering the success of introduction of math infusion within middle schools. In particular, districts with greater administrative support evidenced more successful implementations than schools with limited support.

In summary, both studies demonstrated that math of varying levels of difficulty can be infused into a wide range of 8^{th} grade science topics, despite the fact that the math infusion lessons were often limited by the teachers own experiences and background, and the professional development was not fully optimized, post-lesson reflections of teachers indicated that the math they introduced fit naturally within the science topics and that students expressed few of the anticipated frustrations with the introduction of math into science. Science teachers reported that they would by choice continue to embed math despite their initial resistance to give up science teaching time. Student achievement and attitudinal shifts were documented even though time devoted to mathematics was relatively limited. Lower performing students appeared to gain more than others students. Examination of the pre-post achievement data showed that the observed change was greatest on open-ended questions, questions hypothesized as assessing conceptual learning. Social benefits were also noted. For example, one teacher with many special education inclusion students noted that when a student with special needs found the math easy, the student often gained a new respect from peers.

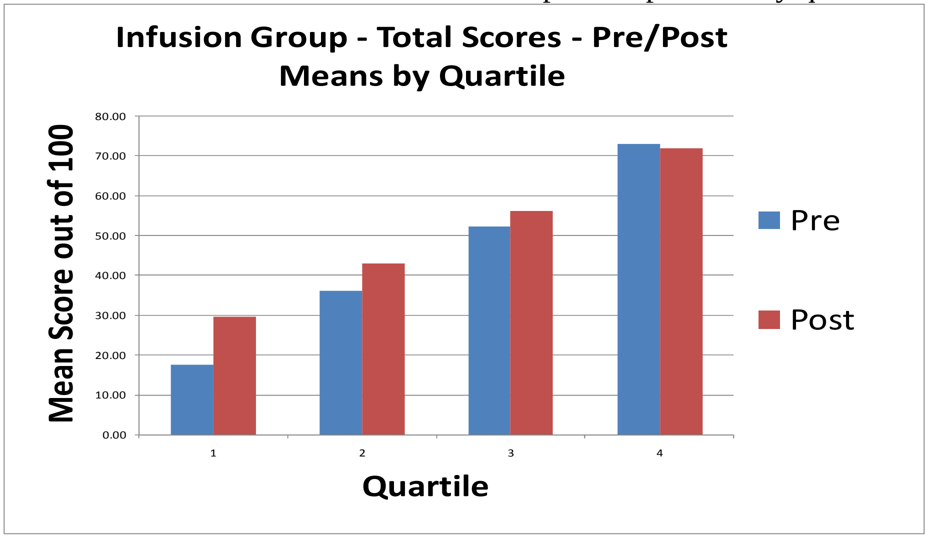
<u>Math Infusion in Engineering/Technology Education:</u> The study of the math infused technology lesson, as with the science intervention, examined changes in student math content knowledge and student attitudes. The content knowledge assessment included both multiple choice and open-ended (rubric scored) questions and data from these two types of items were examined separately and combined. Although these data are still being examined, the results are encouraging.

Student Math Content Knowledge: As can be seem in Table 5 and Chart 1, when students were divided into quartiles based upon their pre-test assessment performance, students in three out of four quartiles show improvement from the pre to post assessment. Performance change is most dramatic for students who scored in lower quartiles.

Table 5. Multiple choice scale quartiles for infusion students (fall 2008).

	Quartile 1	**Quartile 2**	**Quartile 3**	**Quartile 4**
Pre Means	17.51	36.01	52.14	72.83
Post Means	29.52	42.97	56.04	71.77

Chart 1. Infusion students total scores on pre and post test by quartile.



Although further analyses of these data are on-going, preliminary results indicated that when compared to comparison students, infusion students scored significantly higher on two multiple choice questions, all 10 open-ended questions, the multiple choice summed score, the open-ended summed score, and the entire assessment composite score. Match paired t-tests revealed significant differences from pre- to post for infusion students on the composite score, but not for comparison students. However, an independent t-test showed infusion students had greater math content knowledge than the comparison students. See able 6 below for further information.

Table 6. Total score changes in technology infusion and comparison students (fall 2008).

	Infusion Classes (Matched Pre/Post Data) (N = 484)			Comparison Classes (Matched Pre/Post Data) (N= 327)			Infusion v. Comparison (Post Data)		
	Mean Pre	Mean Post	Mean Difference	Mean Pre	Mean Post	Mean Difference	t	df	Mean Difference
Total Score	45.12	50.10	4.98**	37.95	39.57	1.62	6.72	809	10.53**

Note: *p < .05, **p < .01

Next steps

Based on the positive and encouraging findings from both the A/B workshop infusion initiative and the impact studies, a more rigorously developed mathematics infusion curriculum is being proposed that will be driven by decision rules in the current mathematics infusion model. Curriculum development would employ curricula developers as well as teachers and math infusion would be of a longer duration. In addition, more extensive training and supports would be provided to science teachers in order to deliver the curriculum at optimal levels and with less variability. The mathematics content will target for infusion the highly important and problematic content area of algebra.

Conclusion

The model of math infusion into science and technology continues to be refined and enhanced as we learn more from and about the teachers and classes that have adopted this model. Based on what we have learned to date, elements of the math infusion model are:

- The mathematics addresses key areas where students typically have difficult
- Mathematics is relevant and important for the STE
- Mathematics is taught in an inquiry based way, focusing on conceptual understanding rather and formulaic application
- Mathematics is infused into existing inquiry based STE lessons
- Teacher professional development is provided for mathematics content knowledge and pedagogy

The model of math infusion provides a way to conceptualize how teachers can infuse mathematics into science. It provides guidance for both professional development activities and classroom implementation. Data indicate with high quality infusion that lasts for at least 20 days, students evidence increased content knowledge and improved attitudes. Teachers in science report a value added to their content area from enhanced math performance by middle schools students. They also find that math infusion is doable within a regular science curriculum and does not limit what they can teach of their own subject area.

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 wide-spread math infusion.

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