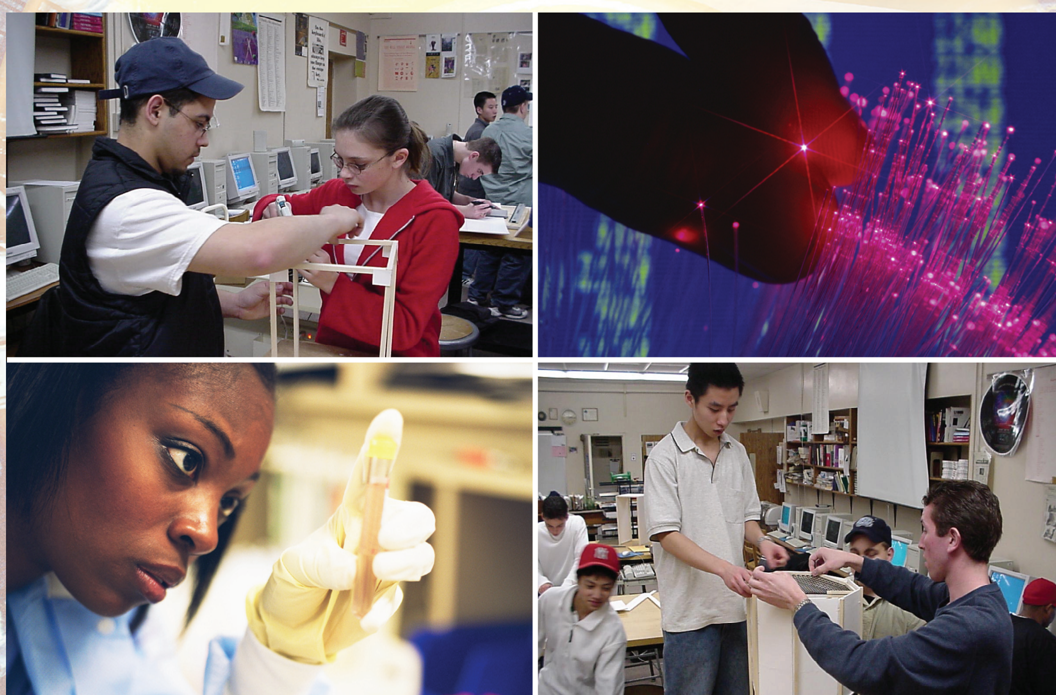
National Science Foundation's
MSTP PROJECT

STEM SYMPOSIUM

Mathematics Infusion into Science, Technology & Engineering



MARCH 5-7, 2009

The Resort at Singer Island, Singer Island, Florida

HOFSTRA UNIVERSITY

NSF/Hofstra CTL Mathematics Infusion into

Symposium

ACKNOWLEDGEMENTS

The success of the STEM Symposium could not have occurred without the support and assistance of many very dedicated and committed people. Lois Miceli, Doris Skura and Jacqueline Scarola helped manage the Symposium logistics, assisting participants with travel, accommodations and responding to numerous queries from all. Susan Perry, of the Perry Group, assisted with finding the location for the Symposium and worked throughout with overall organization of the symposium. She was the go-to person during the meeting, freeing us to focus on what we were learning and on attendees' ideas about the symposium itself. Part of our success can be attributed to the fact we could make changes to our agenda based on progress and suggestions during the meeting. Six research assistants- Maria Russo, Laura Saxman, Theresa Bhoopsingh, Laura Hecht-Felella, Deborah Jaspen, and Oshika Whittaker were essential to our success. These students served as recorders during each of the breakout sessions, and later helped to synthesis and consolidate each team's recommendations into a coherent whole. William Peruzzi and Barbara Kelly assisted us in the final editing of the Symposium Recommendations.

Of all who have provided support, no one has done more than Maria Russo. She worked with us with us for three years as a graduate research assistant on the MSTP project. She was the lead graduate student at the Symposium and took the lead in creating the first drafts of the Symposium Recommendations.

HOFSTRA UNIVERSITY

CENTER FOR TECHNOLOGICAL LITERACY
773 FULTON AVENUE
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Middle School Grades Math Infusion in STEM Symposium

The National Science Foundation supported MSTP Project (NSF #0314910) has produced exciting findings on improving student learning in mathematics through interconnecting and infusing math into middle school science and engineering/technology education classes. The findings indicate that student performance in mathematics can be improved with statistical significance using existing resources. In process of doing so, we developed strategies for creating STEM Learning Communities that are not only self-sustainable, but also support interconnected teaching and learning. However, while our work was completed in a rigorous fashion, it provides a snapshot of what might be accomplished in the future. The Symposium was formed to inform others of our results, but more importantly to engage the STEM community in a dialogue about the necessary steps to further enhance student learning in interconnected STEM education and the required evidence to support change at the local, state, and national levels.

The Middle School Grades Math Infusion in STEM Symposium was held from March 5th —7th, 2009. The primary goal of the Symposium was to develop recommendations and a research agenda for interconnected STEM teaching and learning. Forty-five active researchers in STEM education joined with colleagues from math and science education, assessment, school administrators, and teachers to collaborate in an interactive experience to shape the Symposium objectives from their collective judgment.

The STEM Symposium was guided by a national steering committee that met face-to-face and virtually to provide suggestions in terms of location, the context, and content of the meeting. It was extremely valuable that we had this advice, without it the Symposium would not have been as successful. Not only did we develop recommendations and research agendas, nearly half the attendees have extended their research agendas to include aspects of interconnected STEM and formed new professional collaborations.

We hope you find the report informative and useful.

Sincerely,

Dave Burghardt

Dr. David Burghardt, Ph.D.
Principal Investigator, MSTP

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Executive Summary

The MSTP Project

The Center for Technological Literacy (CTL) at Hofstra University, supported by NSF grant #0314910 (*The Mathematics Science Technology Partnership* — MSTP Project), has reported promising results from infusing mathematics concepts into science, technology, engineering, and mathematics (STEM) curricula at the middle school level in its participating schools. Through infusion, mathematics is introduced into science, technology, and engineering (STE) lessons at critical points so that the infused concepts naturally fit with the concepts and skills taught in the STE content areas. In addition, connections are made between the disciplines. The project did not attempt to combine STEM into a curricular whole, but allowed each subject to maintain its own perspective, with mathematics infused throughout (see Hecht et al. paper in appendix B).

Such successes prompted the project to convene the Mathematics Infusion into Science, Technology and Engineering symposium in March 2009. This two and a half day event brought together more than 45 individuals: STEM researchers; leaders from science, mathematics, engineering, and technology education; assessment specialists; school administrators; and STEM teachers (see list of attendees and biographies in appendix A). Together they proposed new directions in teaching and learning in the middle-level grades, and worked effectively to attain the primary goals of the symposium: exploring the advantages of connecting STEM disciplines, generating recommendations for making connections, and developing a related research agenda for mathematics infusion into STE.

The STEM Symposium

A collaborative dialogue between participants took place throughout the symposium. The first evening provided a context for the symposium as well as insight into MSTP accomplishments. The focus was on mathematics infusion (introducing mathematics into the STE lessons to create interconnections between the disciplines), the silo effect phenomenon (lack of coordination between the different STEM areas in schools), and the MSTP model for sustainable change (showing how to increase middle school student learning). During the morning of day one, a panel reported briefly on papers that explored the challenges of, and opportunities provided by, STEM connections. Small multidisciplinary groups met to develop research questions and recommendations related to the nature of STEM connections. Recommendations were displayed, allowing for comments from other participants, and each group then used the feedback to strengthen their research agendas and recommendations. The structure for the afternoon was similar to that of the morning, but the focus was on creating change in the schools. On day two, participants were offered a choice of four activities: (1) developing a framework for mathematics infusion in STEM research, (2) reviewing and elaborating on symposium recommendations, (3) refining the research questions that emerged on day one, and (4) developing collaborative research proposals.

Symposium Recommendations and Research Agenda

The following recommendations were made:

- ***Develop a research framework for mathematics infusion in STE.***
  Two research areas to be explored are characterizing the mathematics infusion in STE interventions or curricula across grade levels and demonstrating how student learning will be assessed.

- ***Clearly define mathematics infusion in STE.***
  This definition must be compared to and contrasted with mathematics integration and it must delineate what successful mathematics infusion in STE consists of at different grade levels.

- ***Develop or revise curricular materials for mathematics infusion in STE.***
  Curricular materials should be based on research that has identified the mathematics topics that are most relevant at each grade level and the areas where mathematics can be appropriately connected and infused in STE.

- ***Conduct additional research on mathematics infusion in STE.***
  For mathematics infusion to be accepted by stakeholders, administrators, and teachers, more empirical support is needed. Topics to be studied include the infusion model in the classroom, administering the curriculum, effects of infused discipline knowledge, the value of mathematics infusion to the primary subject, and mathematics topics that are easily connected to the STE domains.

- ***Expand the assessment materials related to mathematics infusion in STE.***
  Further research must document whether infusion will improve student scores on existing assessments and whether new assessments must be developed. New assessments must allow for the unique contributions of mathematics infusion. Assessments may be targeted toward STE knowledge; infused discipline knowledge (mathematics); unique student outcomes; improvement in student attitudes, self-efficacy, and engagement toward STEM; and the likelihood of students pursuing further studies and/or careers in STEM-related fields.

- ***Determine the most effective preservice training for mathematics infusion in STE.***
  Education for K–12 STEM teachers will likely have to incorporate mathematics infusion. Preservice training programs should include additional courses, time devoted to mathematics content and pedagogy, and/or a specialized mathematics infusion course.

- ***Establish the most effective professional development for STE teachers to engage in mathematics infusion.***
  Professional development (PD) must prepare STE teachers for mathematics infusion instruction. Research should focus on what type of PD is most successful for mathematics infusion (e.g., stand-alone workshops, collaborative STEM learning communities, and/or additional mathematics content and pedagogy training).

- ***Create a systemic change in the emphasis of STEM disciplines.***
  This may be the most important recommendation for mathematics infusion in STE. NSF must consider funding and implementing a STEM research and development agenda that deals with connected STEM disciplines and mathematics infusion. Another recommendation

calls for revision of national science standards so that they focus on fewer topics in greater depth, and development of new standards that produce a logical pre-K–12 sequence for learning.

Conclusion

The symposium participants worked effectively to create recommendations and research agendas. They successfully extended their own research plans and efforts to include aspects of mathematics infusion and interconnected STEM. Moreover, they endorsed the format of the symposium, and were challenged and intrigued by the conversations that developed. Due to new relationships that emerged, numerous participants collaborated on grant proposals to investigate topics or research questions that had been recommended (see appendix D). Overall, the STEM symposium was a productive meeting of top professionals that not only promoted insights into interconnected STEM and mathematics infusion but also developed essential recommendations and research agendas to advance and connect the STEM disciplines.

STEM Symposium Report

Interconnected mathematics and science education instruction is an enduring concept; there have been diverse rationales, curricula, and research studies illustrating such interconnected teaching and learning throughout the years. More recently, these attempts to interconnect have been expanded to include technology and engineering education. What is now being sought is instruction that features stronger interconnections among the disciplines represented by the acronym STEM: science, technology, engineering, and mathematics. Despite continuing attempts at interconnection, these fields have yet to establish a clear exposition of the benefits of interconnected instruction. Nor do they have the means to develop, implement, assess, and research interconnected STEM teaching and learning. STEM areas continue to be taught in unconnected ways in the schools, even in the middle-level grades, where these connections would be especially beneficial.

To address the need for further development of interconnected instruction for STEM disciplines, the Center for Technological Literacy (CTL) at Hofstra University, supported by NSF grant #0314910 (*The Mathematics Science Technology Partnership* — MSTP Project), hosted a symposium, Mathematics Infusion into Science, Technology and Engineering, in March 2009. This event brought together more than 45 prominent individuals: STEM researchers; leaders from science, mathematics, engineering, and technology education; assessment specialists; school administrators; and STEM teachers (see list of attendees and biographies in appendix A). Together they proposed new directions in teaching and student learning through connecting the STEM disciplines, particularly in the middle-level grades.

STEM Symposium Overview

The STEM symposium was a two and a half day gathering that allowed time for participants to put forward key aspects of their own disciplines and support one another in establishing connections between the STEM fields. In order to do so, the symposium was purposely structured to create a collaborative dialogue between participants having different interests and expertise. Whole group presentations and discussions were minimized, and emphases were placed instead on short paper presentations, smaller multidisciplinary discussion groups, and poster presentations developed during the discussion groups. The primary goals of this groundbreaking event were to explore the advantages of connecting STEM disciplines, generating recommendations for making the connections, and developing a related research agenda for mathematics infusion into STE. These goals focus on the middle-level grades.

The first evening of the symposium provided a context for the work to be developed, and offered insight into the accomplishments of the MSTP Project. Principal investigators, consultants, and administrators from MSTP opened the symposium by presenting a background for interconnected learning in STEM. The term "mathematics infusion," describing the approach that MSTP used to make mathematics interconnections between the STE disciplines, was defined and discussed. Through infusion, mathematics is introduced into the STE lessons at critical points so that it naturally fits with the concepts and skills that are taught in the STE content areas; in addition, interconnections are made between the disciplines. 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.

The silo effect phenomenon was also discussed that evening. This phenomenon describes a lack of communication and connectedness between departments in an organization, and is apparent in the lack of connection between STEM disciplines in the schools. Due to insufficient coordination between the different STEM areas in the schools, each individual discipline typically moves forward with its own goals and plans but ignores the needs and importance of the others. When this happens, not only do information and meaning get lost, but students fail to see connections and relevance between STEM content areas. Establishing connections through mathematics infusion is the methodology that the MSTP Project chose to break down the existing STEM silos. Symposium participants were encouraged to reflect on ways to further the mathematics infusion agenda, and to consider additional means of breaking down the barriers that inhibit attempts to interconnect STEM instruction.

Later in the evening, members of the MSTP Project team highlighted promising results from the five years of the project, focusing on how the project improved mathematics teaching and learning in middle schools in New York State. They presented the positive results of the project's impact study of the effects of mathematics infusion in science and technology eighth-grade curricula. This study found that students experiencing such infusion not only demonstrated increased knowledge of mathematics concepts but also developed an improved attitude toward mathematics. There were statistically significant improvements in student mathematics ability, particularly for the bottom half of the classes. Further, when a learning community component was added to the professional development mathematics infusion model for middle school STEM teachers, these teachers experienced growth in their understanding of how to infuse mathematics into STE. They also changed their opinions of the importance of mathematics within STE, and valued being part of collaborative STEM learning communities (see Hecht et al. paper in appendix B).

During the morning of day one, the symposium participants were led further into an overview of the nature of STEM connections. A panel of participants reported briefly on papers to the larger group to introduce potential challenges and opportunities of STEM connections. These papers included suggestions for interconnected teaching in STE curricula, an exposition on pressing issues in interconnected STEM, and results from an integrated mathematics and science project (see appendix B). After these presentations, six breakout groups of eight participants each met to develop research questions and recommendations related to the nature of STEM connections. These groups were intentionally designed to comprise participants from various STEM fields and different professional backgrounds. Included in each group was a facilitator who was a member of the STEM steering committee, as well as a graduate student scribe who recorded the exchange of ideas between participants. In each of these breakout groups, participants prepared a poster that featured the recommendations and research questions they had collaboratively developed. These posters were later displayed for the whole group, allowing participants from all breakout groups to critique and comment on the recommendations and research agendas. After participants provided written feedback on all six posters, each breakout group reconvened to reflect on the constructive criticism they had received, and to recompose research agendas and recommendations accordingly.

The structure for the afternoon of day one was similar to that of the morning. Discussion began with a panel of participants presenting their papers, but this time the emphasis was on creating change in schools. More specifically, these papers focused on the challenges and benefits of mathematics infusion, an integrated mathematics and science teacher preparatory model, and the creation of an innovative integrated technology/engineering curriculum for elementary schools (see appendix B). Subsequently, as in the morning, six different multidisciplinary breakout groups of eight participants each plus scribes met for discussion. The focus of these sessions was to develop recommendations and research questions related to creating change in schools. Again, posters were developed, critiqued, and revised.

On day two, the participants were offered a choice of four activities: (1) developing a framework for mathematics infusion in STEM research, (2) reviewing and elaborating on symposium recommendations, (3) refining the research questions that emerged on day one, and (4) developing collaborative research proposals (start-up funding of $2,500 per participant to support development and implementation of these plans was made available later). The breakout group deliberations from day one informed individuals' choices for participation in projects during day two. For instance, when associations were made between participants who shared similar interests during the first day and a half, these individuals chose to collaborate to create preliminary research proposals. Also, several participants developed new interests in specific mathematics infusion–related areas and chose to work on projects that melded these interests. Examples of such projects included creating recommendations for school-based change and developing a research framework for mathematics infusion.

Recommendations and Research Questions for Mathematics Infusion and Interconnected Teaching and Learning in STEM

The development of mathematics infusion–related recommendations and research agendas was the crux of the STEM symposium. It became clear during participant discussions, presentations, and deliberations that more research related to interconnected teaching and mathematics infusion is essential to further develop interconnected STEM teaching and to negate the STEM silo effect. The recommendations that were developed, along with related research questions, are presented below.

Develop a research framework for mathematics infusion in STE.

The issues that arise in creating a STEM research framework are similar to those involved in creating other educational research frameworks. For example, research involving mathematics infusion in STE would undoubtedly benefit from additional descriptions of research questions, improved outcome measures, and designs that easily attribute outcomes to mathematics infusion. Nevertheless, there are two vital research areas that should be explored to further mathematics infusion in STE and interconnected teaching. First, it is necessary to characterize the mathematics infusion in STE interventions or curricula across grade levels. Determining the extent to which the STEM disciplines can logically and practically be interconnected, defining the roles and responsibilities of teachers from each discipline in the development and implementation of infusion materials, and deciding whether infusion is best as a separate curriculum or as a way to supplement the existing STEM curricular materials must all be established.

The second crucial step is to characterize how student learning will be assessed. It seems clear that existing standardized instruments do not capture the benefits of interconnected instruction and mathematics infusion. Thus relevant, reliable, and valid assessment tools that tap into the key elements of mathematics infusion must be developed. Both areas will be elaborated on in later recommendations. The following research questions related to the development of a mathematics infusion framework were generated:

- What are the characteristics of mathematics infusion in STE interventions/curricula that would be most successful in increasing student mathematics learning?
- Who would be more successful in implementing mathematics infusion curricula: a mathematics teacher, an STE teacher, or both?
- What is the best way to logically and practically align STEM disciplines?
- What is the extent of interconnectedness between mathematics and science, technology, and engineering concepts? For example, which concepts overlap in STEM?
- What areas should be assessed through mathematics infusion into STE? (Examples of such areas are mathematics, STE, mathematics teacher and student self-efficacy, and problem-solving ability.)

Clearly define mathematics infusion in STE.

As many participants noted throughout the symposium, mathematics infusion and mathematics integration have taken on a plethora of meanings. These discrepancies cause difficulty not only in understanding what each term means but also in synthesizing existing research results. Therefore, a clear and succinct definition of mathematics infusion in STE disciplines should be developed. Further, this mathematics infusion definition must be compared to and contrasted with mathematics integration in order to document the definition's benefits. The following research questions regarding the development of a definition of mathematics infusion in STE were generated:

- What student outcomes occur when you infuse mathematics into STE? How do they compare with the outcomes that occur when you integrate mathematics and STE into a curricular whole?
- Which model or definition of mathematics infusion in STE is most effective in increasing student learning?
- How is mathematics infusion applied across grade levels? For instance, what does successful mathematics infusion in STE look like at different grade levels (elementary, middle school, and high school)?

Develop or revise curricular materials for mathematics infusion in STE.

First and foremost, there is a need to determine whether STE curricular materials that have mathematics infused throughout already exist. If such materials have in fact been developed, the extent to which the included mathematics is relevant and accurate should be assessed. If these materials are found to be unsatisfactory or ineffective, they should be either revised or ignored. In the place of the unsatisfactory curricular materials, and where no curriculum exists, new materials must be developed for all grade levels. These materials should be based on research that has identified the mathematics topics that are most relevant for each grade level and the areas where mathematics can be appropriately connected and infused. The following research questions related to the development of mathematics infusion in STE curricular materials were generated:

- What are the different delivery approaches of adding mathematics infusion into curricula? Which ones are most effective?
- What are the characteristics of mathematics-infused curricula that lead to increased success in student learning outcomes for the mathematics content?
- To what extent can STEM curricular materials that have been developed for after-school programs be applied to mathematics infusion curricula used in K–12 classrooms?
- What type of pedagogy (e.g., constructivist or traditional, implied or specified) is most beneficial when using mathematics infusion in STE disciplines?
- What does implementation of high-quality mathematics infusion look like when it occurs in the STE classroom?

Conduct additional research on mathematics infusion in STE.

It is necessary to specify what is meant by mathematics infusion and develop optimal mathematics-infused curricula. In addition, it is essential to expand existing empirical research and encourage acceptance of mathematics infusion by stakeholders, administrators, and teachers. Further, the effects of infused discipline knowledge and skills should be examined; for instance, when mathematics is infused into STE, the benefits of teaching the targeted mathematics concepts must be determined. The value that mathematics infusion adds to the primary subject should also be examined; what mathematics will add to STE content, for example, should be considered. Finally, the specific mathematics topics that are easily connected to the separate domains of STE should be identified. The following research questions related to mathematics infusion in STE disciplines were generated:

- What are the major concepts in STEM and how do they overlap with core knowledge in each of the disciplines?
- Which teachers are most effective at carrying out infusion and interconnectedness: those who follow textbooks or those who do not?
- What are the effects on teachers who teach in an infusion classroom? Will their mathematics self-efficacy increase? Will they be more motivated to try new ideas and methods? Will they be more satisfied when teaching their curriculum?
- What are the most successful ways to convince teachers and students that mathematics infusion into STE is doable, makes sense in the classroom, and benefits the students?
- What are the specific barriers to mathematics infusion in STE and how can these barriers be overcome?

Expand the assessment materials related to mathematics infusion in STE.

In the current age of high-stakes testing, assessment is a critical issue for administrators, teachers, and parents. Therefore, it is important to study the various ways to assess student and teacher outcomes for mathematics infusion. Further research should be conducted and documented to show how infusion supports student performance on existing assessments, and to demonstrate whether infusion can improve student scores on such assessments. The main focus should be on finding the best ways to assess the unique outcomes of infusion and determining the extent of need for different assessment tools is also important. Assessments may be targeted toward (1) primary discipline knowledge (STE); (2) infused discipline knowledge (mathematics); (3) unique student outcomes (e.g., creating designs, seeing connections within disciplines, solving problems); (4) improvement in student attitudes, self-efficacy, and engagement toward STEM; and (5) the likelihood of students pursuing further studies and/or careers in STEM-related fields. The following research questions related to assessment were generated:

- How can we use assessments to capture achieved student outcomes (STE understanding, mathematics understanding, connected knowledge, complex problem solving, engagement, and efficacy) from mathematics infusion in STE learning?
- How do we assess the claim that interconnected STEM teaching and mathematics infusion into STE will foster student learning of STEM? That is, how do we document that mathematics infusion is superior to unconnected learning in STEM?

Determine the most effective preservice training for mathematics infusion in STE.

To further the effectiveness of mathematics infusion in STE, the ways in which K–12 STEM teachers are being educated must change. For STE teachers to teach mathematics properly, additional courses and/or time devoted to mathematics content and pedagogy will probably need to be emphasized in preservice training programs. Furthermore, the development of specific mathematics infusion in STE courses and mathematics infusion practicum experiences will benefit preservice teachers once they use mathematics infusion in their own teaching. The following research questions related to teacher preparation were generated:

- How does the background of preservice teachers (course work, practicum, prior experience, etc.) relate to what they do in the classroom? What effect does such a background have on how they teach?
- What preservice training is needed to promote interconnected STEM teaching and mathematics infusion in STE areas?
- What are effective strategies to prepare preservice teachers to use mathematics infusion techniques?
- How is mathematics infused into existing content courses in STE for preservice teacher education and into existing pedagogical courses?
- How would the National Council for Accreditation of Teacher Education (NCATE) standards need to be altered to incorporate interconnected content knowledge for STEM teachers?

Establish the most successful professional development for STE teachers to engage in mathematics infusion.

Adequate professional development (PD) must be provided to prepare STE teachers for delivery of mathematics infusion instruction. First, the type of PD that will be successful, and the ways that this PD will be delivered to teachers, must be specified. For example, research is needed to determine whether PD should consist of stand-alone workshops, collaborative STEM learning communities, additional mathematics content and pedagogy training, or a combination of the three. It is unclear now which methods are most successful. Developing effective PD can be accomplished through studying mathematics infusion from a professional development perspective: using a lesson study approach, or documenting various types of PD that prepare teachers for mathematics infusion, might work well. It is essential to identify what STE infusion teachers need to teach interconnected mathematics at the same level as master mathematics teachers, and what opportunities for follow-up should be provided. The following research questions related to professional development were generated:

- What are the most effective professional development methods for mathematics infusion in STE?
- What are effective strategies in overcoming teacher resistance, particularly science teacher resistance, to professional development for mathematics infusion?
- What administrative, practical, and structural models would be most effective in supporting mathematics infusion in STE?
- How can schools provide sufficient opportunities for STEM teachers to communicate with each other as they link their subject areas?
- To what extent must teachers from one domain (e.g., science or technology) know the others' content and pedagogy (e.g., mathematics) to engage effectively in infusion attempts?
- What can be done to foster a greater knowledge base in STE and help teachers leverage their current expertise while taking on and incorporating mathematics into their curricula?

Create a systemic change in the emphasis of STEM disciplines.

A profound recommendation for systemic change in teaching and learning STEM disciplines is to encourage mathematics infusion attempts. Participants offered multiple suggestions to allow for such a change. One was that the National Science Foundation (NSF) should consider implementing a STEM research and development agenda that systematically deals with connecting STEM disciplines through mathematics infusion. Another suggestion called for revision of national science standards to focus on fewer topics in greater depth, and development of new standards for STE that would incorporate a logical pre-K–12 sequence for learning (similar to the sequence for mathematics). In doing so, the goal would be to promote consistency in what is taught at specific grades across different schools and for students to develop deeper understandings and more complex STEM content mastery. Additional suggestions were to encourage multidistrict collaborations and promote university–school district partnerships to facilitate mathematics infusion. Through this kind of collaboration, the necessary support for successful implementation of mathematics infusion will most likely take place. The following research questions related to creating systemic change in emphasizing STEM disciplines were generated:

- What are the attributes of administrator support (time, physical proximity, etc.) that will support a sustainable model of mathematics infusion in the schools?
- How can connections outside the school building (e.g., industry partnerships) be fostered to support interconnectedness between STEM and mathematics infusion?
- What are ways in which conversations between faculty members at universities and educators in the schools can be promoted?
- What would be the impact of interconnected STEM as a component of national standards in science, mathematics, and engineering/technology education?
- How do the STEM standards need to be changed to foster the integration of STEM content?
- What are effective marketing strategies for integrated STEM curricula? Can social networking models be used to develop, market, and sustain interconnected STEM materials?

Participant-Developed Research Proposals

As mentioned previously, participants were encouraged to develop collaborative research proposals for further investigation into interconnected STEM and mathematics infusion in STE. Fourteen proposals were developed, with a total of 20 participants collaborating on these projects. Many participants focused on piloting research studies, while others concentrated on creating grant proposals to the National Science Foundation and/or other granting agencies. Remarkably, almost all of the proposals sought to investigate a topic or research question that was recommended during the STEM symposium (e.g., mathematics infusion PD and preservice models, mathematics infusion–related STE curriculum development, mathematics infusion assessment materials). The full details of these proposals can be found in appendix C.

Participant Reflections and Future Implications

At the conclusion of the STEM symposium, all participants were asked to reflect on the quality of their involvement in the previous two and a half days, focusing on the symposium's format, important concepts in STEM education, and next steps to take. In consolidating the participants' written reflections, recurring thoughts, issues, and themes surfaced. The majority of these were related to the recommendations and major ideas that had been discussed during the symposium. Ideas mentioned included the need for a shared or unified definition of mathematics infusion, further investigation into the body of accumulated research evidence and valid assessments to determine whether mathematics infusion works, and a delineation of the preeminent ways to prepare teachers to infuse mathematics into STE.

Participants noted that the symposium was not only "most helpful" and "highly informative" but also necessary for moving the interconnection of STEM disciplines forward. The vast majority of participants indicated that it was a "pleasure" and an "honor" to be in the company of talented cohorts. They noted that their participant-colleagues had shared their thoughts about their respective disciplines and that this sharing had generated interesting conversations about interconnected STEM. A few participants explicitly mentioned that they were "grateful" and "excited" to be part of a mathematics infusion effort, and that they would "look forward to continued participation" and "the next steps" in mathematics infusion and interconnected STEM developments.

Participants were challenged, intrigued, and grateful for the conversations that developed during the multidisciplinary small groups. As one participant reflected, "It has been a bit of time since I had thought outside my domain and looked at issues from the multiple perspectives of the group, and I was frustrated yet I found it enjoyable being in a group where perspectives differed. The process caused me to reflect on my own understandings of infusion, systematic change, and professional development." Furthermore, some participants indicated that they learned much from those who made more formal presentations, while others noted that they found the readings in the symposium briefing book helpful in stimulating their thinking. Still others found especially interesting the points of view and particular ideas of "infusion" held by colleagues from other fields. Overall, most of the participants involved in the STEM symposium found the experience to be a great opportunity to work collaboratively with a variety of people who represented multifaceted perspectives.

Conclusion

The STEM symposium participants effectively worked together to create recommendations and related research agendas. Participants were successful in extending their own research plans and efforts to include aspects of mathematics infusion and interconnected STEM. Moreover, participants endorsed the format and structure of the symposium. They described positive and fruitful elements of the symposium that included a focused topic of middle-level mathematics infusion and interconnected STEM that had appeal to a broad constituency; a small number of participants from various areas of expertise and content fields; the interactive proceedings that provided time for small group deliberations and encouraged communicating and learning from one another; and the encouragement to form new collaborations with colleagues present at the symposium. All of this combined resulting in a productive meeting of top professionals, researchers, and educators, where insights into interconnected STEM and mathematics infusion occurred, and essential recommendations and research agendas were developed to advance and connect the STEM disciplines.

Perhaps the most important recommendations for mathematics infusion involve encouraging systemic change in the teaching and learning of the STEM disciplines:

- The National Science Foundation is urged to implement a STEM research and development agenda that systematically deals with connected STEM disciplines and mathematics infusion.
- It would be beneficial to revise national science standards so that they focus on fewer topics in greater depth, and to develop new standards for STE that would incorporate a logical pre-K–12 sequence for learning.
- If further research verifies that interconnected STEM and mathematics infusion do improve student learning sufficiently, then relevant curricula and professional development should be initiated in order for mathematics infusion and interconnected STEM implementation in schools to become widespread.

The superintendents, teacher practitioners, and STEM faculty members in attendance believe that teachers, given adequate support, would embrace such changes because students would learn STEM more effectively and at a deeper and more meaningful level. To participants, the concept of interconnected learning, and particularly the issue of mathematics infusion, is not only beneficial for student learning but also achievable.

Appendix A

List of attendees and biographies

List of Attendees

First Name	Last Name	Department	Institution
Paul	Adams	Professor of Physics and Anschutz Professor of Education	Fort Hays State University
Taryn	Bayles	Professor, Chemical & Biochemical Engineering	University of Maryland, Baltimore County
Donna	Berlin	Professor, The School of Teaching and Learning	The Ohio State University
M David	Burghardt	Professor, Department of Engineering	Hofstra University
Beverly	Clendening	Professor, Biology Department	Hofstra University
Jere	Confrey	Distinguished Professor, Department of Mathematics, Science and Technology Education	North Carolina State University
Christine	Cunningham	Vice President of Research and Educator Resource Development	Museum of Science, Boston
Chad	Dorsey	Incoming President	The Concord Consortium
Paul	Eakin	Professor, Department of Mathematics	University of Kentucky
Allan	Feldman	Professor, Science Education and Teacher Education	University of Massachusetts
Linnea	Fletcher	Program Officer	National Science Foundation
Bert	Flugman	Director	CASE/CUNY Graduate Center
Alan	Gerstenlauer	Superintendent of Schools	Longwood Central School District
Michael	Hacker	Co-director, Center for Technological Literacy	Hofstra University
Mark	Hardy	Assistant Professor, Department of Technology	SUNY Oswego
Sandra H.	Harpole	Associate Vice President for Research and Professor of Physics	Mississippi State University
Deborah	Hecht	Associate Director	CASE/CUNY Graduate Ctr
Marie	Hoepfl	Department of Technology	Appalachian State University
Michael	Jabot	Professor, Physics & Science Education	SUNY Fredonia
Craig	Kesselheim	Senior Consultant	Mitchell Institute-Great Schools Partnership
Doris	Kimbrough	Associate Professor, Department of Chemistry	UC Denver
Janet	Kolodner	Professor, Computer Science Department	Georgia Institute of Technology
Glenda	Lappan	Distinguished Professor, Division of Mathematics and Science Education	Michigan State University
Richard	Lehrer	Professor of Science Education	Vanderbilt Peabody College
Jim	Lewis	Department of Mathematics and Statistics	University of Nebraska Lincoln

First Name	Last Name	Department	Institution
Marcia C.	Linn	Professor of Development and Cognition	Graduate School of Education, University of California, Berkeley
Michal	Lomask	Science and Assessment State Consultant	Connecticut State Education Department
Scott	McMullen	K12 Science Coordinator	Manhasset Central School District
Ramakrishnan	Menon	Professor, Mathematics Education	California State University Los Angeles
Mitchell	Nathan	Professor, Department of Educational Psychology, Curriculum & Instruction, and Psychology	University of Wisconsin-Madison
Greg	Pearson	Senior Program Officer	National Academy of Engineering
Theodora	Pinou	Department of Biological and Environmental Sciences	Western Connecticut State University
Gerhard	Salinger	Program Officer	National Science Foundation
Mark	Sanders	Professor, Integrative STEM Education	Virginia Tech
William	Schmidt	Department of Statistics & Probability, College of Education	Michigan State University
Christian	Schunn	Psychology Department	University of Pittsburgh
Kendall	Starkweather	Executive Director	International Technology Education Association
Gay	Stewart	Associate Professor, Department of Physics	University of Arkansas
Bruce	Torff	Professor of Curriculum and Teaching	Hofstra University
Alan	Tucker	Distinguished Teaching Professor, Department of Applied Mathematics and Statistics	SUNY at Stony Brook
Linda	Walker	Former mathematics middle school teacher	Mathematics Consultant, Tallahassee Florida
Iris	Weiss	President	Horizon Research Inc.
Kenneth	Welty	Professor, School of Education	University of Wisconsin-Stout
Arthur	White	Professor, The School of Teaching and Learning	The Ohio State University
Sharon	Whitton	Professor, Department of Curriculum and Teaching	Hofstra University
Jennifer	Wilhelm	Associate Professor, College of Education	Texas Tech Universit
Karen	Zuga	Professor, The School of Teaching and Learning	The Ohio State University

Attendee Biographies

Paul Adams

Paul Adams is a Professor of Physics and Anschutz Professor of Education at Fort Hays State University in Hays, KS. He received his B.S. Degree in Physics and Mathematics from Heidelberg College, Tiffin, OH; MS Degree in Physics from Washington State University, Pullman, WA; and PhD Degree in Science Education from Purdue University, West Lafayette, IN. He received the National Science Teacher Association Distinguished Teaching Award in 2008.

Dr. Adams' primary areas of interest have been science teacher development, technology use in the classroom, inquiry-based instruction. As part of his work he has developed integrated mathematics and science instruction to emphasize the interconnection between mathematics and science. He has developed and taught integrated mathematics and science courses for university students and works with secondary and middle school teachers in developing science lessons integrated with mathematics.

Taryn Melkus Bayles

Taryn Melkus Bayles is a Professor of the Practice of Chemical Engineering in the Chemical and Biochemical Engineering Department at the University of Maryland Baltimore County (UMBC). She has spent ten years working in industry with Exxon, Westinghouse and Phillips Petroleum. Her industrial experience has included process engineering, computer modeling and control, process design and testing, and engineering management. She has also spent 15 years teaching Chemical Engineering at the University of Nevada Reno, University of Pittsburgh, University of Maryland College Park and UMBC. In her courses she incorporates her industrial experience by bringing practical examples and interactive learning to help students understand fundamental engineering principles.

Her current research focuses on Engineering Education and Outreach. The goal of this research is to increase awareness of and interest in pursuing engineering as a career, as well as to understand what factors help students be successful once they have chosen engineering as a major. She is the co-author of the *INSPIRES* (*In*creasing *S*tudent *P*articipation, *I*nterest and *R*ecruitment in *E*ngineering & *S*cience) curriculum which introduce high school students to engineering design through real-hands-on experiences and inquiry-based learning with real world engineering design challenges. This curriculum targets the International Technology Education Association Standards as well as national standards in science and mathematics. She is an Affiliate Professor for Project Lead the Way. She received BS degrees in Chemical Engineering, Mathematics and Chemistry from New Mexico State University; MS degrees in Chemical Engineering and Petroleum Engineering; and a PhD in Chemical Engineering from the University of Pittsburgh.

Donna F. Berlin

Donna F. Berlin holds a BS in elementary education and psychology from Syracuse University, a MA in elementary education and guidance from New York University, and a PhD in early and middle childhood education with emphases in mathematics and research from The Ohio State University. She has taught at the elementary school level and has taught courses in mathematics and science education for elementary, middle school, and secondary preservice and inservice teachers at The Ohio State University for 30 years. In addition, Dr. Berlin spearheaded the development of The Ohio State University Middle Childhood Licensure Program and served as the Middle Childhood Program Coordinator.

Dr. Berlin's research interests include mathematics education, the integration of mathematics and science education, action research, and brain hemisphericity related to instruction. Dr. Berlin is internationally recognized for her pioneering work in the area of the integration of mathematics and science education. She has published in both mathematics and science journals and books and has been invited to present papers at conferences and universities in 23 countries. She received the School Science and Mathematics Association Award for Excellence in Integrating Science and Mathematics.

A leader in both the mathematics and science community, Dr. Berlin served as the Mathematics Education Associate for the Eisenhower National Clearinghouse for Mathematics and Science Education, Principal Investigator and Research Coordinator for The National Center for Science Teaching and Learning, and President of the School Science and Mathematics Association. She was Co-Principal Investigator for the influential National Science Foundation/School Science and Mathematics Association Wingspread Conference: A Network for Integrated Science and Mathematics Teaching and Learning. Also, she has served as an external evaluator and a consultant for numerous mathematics and/or science grants supported by the National Science Foundation and the Department of Education.

Currently Dr. Berlin serves on the Advisory Board for the Whitaker Center for Science, Mathematics, and Technology Education at the Florida Gulf Coast University, Fort Meyers, FL. Also, she serves as the Mathematics Content Expert for the Education Resources Information Center (ERIC), Washington, DC.

David Burghardt

Dr. David Burghardt is a Professor of Engineering, a licensed Professional Engineering in New York and a Chartered Engineer in the United Kingdom. He is also co-Director of the Hofstra University Center for Technological Literacy. He is the former chair of the engineering and computer science departments, and the author of eleven texts in engineering and secondary school technology education. Dr. Burghardt has published numerous articles in professional journals and made many presentations at national engineering and educational conferences. He established the Center for Technological Literacy in 1989 and has continued to expand its role as a national center, and now serve as a co-Director. Since 1993 through the Center he has been a PI or co-PI on seven major NSF grants. All deal in different ways with technological literacy in STEM, of interconnecting STEM disciplines. One of the current projects is about developing virtual modeling in a gaming environment as a way to enhance student understanding of design and mathematical modeling.

Of particular interest to Dr. Burghardt is how engineering design can provide enhanced student learning in mathematics and science, especially for lower performing students. In addition to developing engineering courses at the university level, Dr. Burghardt cocreated the master's degree in MST for in-service teachers, teaches a course in children's engineering to elementary school teachers, and co-directs their action research projects. Over 300 teachers have graduated from the program.

Beverly Clendening

Beverly Clendening, Ph.D., Associate Professor of Biology, Hofstra University, is broadly trained biologist with a Ph.D. in Neuroscience from the University of Michigan and research experience in neurophysiology, developmental biology, molecular biology and biochemistry. Her present laboratory research project explores possible mechanisms underlying temperature-dependent sex determination in reptiles. She teaches an Introductory Cell Biology and Genetics course for freshmen biology majors and also teaches upper-level Developmental Biology and Neurobiology.

Over the last 10 years Dr. Clendening has been experimenting with different approaches to teaching biology. She is presently completing the analysis of a study the compares learning outcomes in lecture only vs. lecture/group problem-solving class format for teaching introductory biology. Five years ago Dr. Clendening was awarded an NSF-CCLI grant to reform the biology curriculum at Hofstra. This grant allowed us to create a new four-course core biology curriculum. Each of the four core courses includes inquiry-driven laboratories and problem-solving workshops.

Her present undergraduate curriculum projects include the creation of a peer-taught interdisciplinary problem-solving course for science and math majors and of a Masters Program in Biology Education. She was involved in the Hofstra/Stony Brook MSTP project for Math Infusion in Science for 3 years, and worked with teachers to align the science curricula with state and national standards and to develop lessons plans that incorporated appropriate math content into science lessons. In addition, Dr. Clendening helped develop and run workshops that engaged teachers in model lessons that incorporated math content in science lessons. At these workshops participants also reviewed and critiqued lessons that were designed by the participating teachers. She is also involved in the GENA (Geneticist-Educator Network of Alliances) that pairs university faculty with high school teachers to improve genetics education in high schools. In her spare time she enjoys running, reading voraciously and chauffer my son to his numerous activities.

Jere Confrey

Dr. Jere Confrey is the Joseph D. Moore Distinguished Professor of Mathematics Education at North Carolina State University and a senior scholar at the William and Ida Friday Institute for Educational Innovation. She is building diagnostic assessments on rational number reasoning using a learning trajectories approach. She chaired the NRC Committee which produced On Evaluating Curricular Effectiveness, and was a coauthor on the NRC's Scientific Research in Education. She was a co-founder of the UTEACH program at the University of Texas in Austin, and founded the Summer Math and Summer Math for Teachers programs at Mount Holyoke

College. She has taught school at the elementary, secondary and postsecondary levels. She received a Ph.D. in mathematics education from Cornell University.

Christine Cunningham

Dr. Christine Cunningham is the Vice President of Research & Educator Resource Development the Museum of Science, Boston where she oversee curricular materials development, teacher professional development, and research and evaluation efforts related to K-16 engineering and science learning and teaching. Her projects focus on making engineering and science more relevant, understandable, and accessible to everyone, but especially marginalized populations such as women, underrepresented minorities, and people with disabilities. She is particularly interested in the ways that the teaching and learning of engineering and science can change to include and benefit from a more diverse population.

Dr. Cunningham's projects span the elementary to community college educational continuum. Principal among these is *Engineering is Elementary (EiE),* a program she founded in 2003. EiE is creating a research-driven, standards-based, and classroomtested curriculum that integrates engineering and technology concepts and skills with elementary science topics. Connections are also made with literacy, social studies, and mathematics. EiE also helps elementary school educators enhance their understanding of engineering concepts and pedagogy through professional development workshops and resources. As the Director of EiE, Christine is responsible for setting the vision and strategy for the project for securing its funding.

Dr. Cunningham has secured over $21 million in grant funding to support her projects and research. Currently, she serves as the Chair of the Advisory Committee for the National Center for Engineering and Technology Education, and is a past-President of the American Society for Engineering Education K-12 and Pre-college Division. Most recently she has been honored with the Outstanding Leadership Award from the American Society of Engineering Education K-12 Division, the Mary Margaret Scoby Award from the Technology Education for Children Council of the International Technology Education Association, and cited as a Leader to Watch by the International Technology Educational Association. Dr. Cunningham earned a joint BA and MA in Biology summa cum laude from Yale University and a PhD in Science Education from Cornell University.

Chad Dorsey

Chad Dorsey is the President and CEO of the Concord Consortium, a non-profit company based in Concord, MA committed to realizing the educational potential of technology, with a specific emphasis on STEM education. Chad Dorsey has recently assumed the role of president at the Concord Consortium, coming to Concord from his previous role as a science and educational technology specialist the Maine Mathematics and Science Alliance (MMSA). At MMSA, Chad developed a variety of STEM education programs, most recently starting a statewide engineering education network fostering collaboration among high schools and technical education centers through student-led sustainable energy projects.

Chad's background is equally spread among in physics, technology and education. He completed an M.A. and doctorate coursework in physics at the University of Oregon, where his research interests included the geophysics of fluids and granular materials. Chad has taught science in middle schools, high schools and college laboratories from Oregon to Munich, Germany, and has been a bona-fide computer geek since he
typed his first BASIC program into an Apple II plugged into his television set.

Paul M. Eakin

Paul Eakin received his 1968 Ph.D. in mathematics from Louisiana State University. His dissertation in commutative algebra was written under the direction of H.S. Butts. Following a postdoctoral year at the University of Rochester, he joined the mathematics faculty of the University of Kentucky where he was Professor of Mathematics since 1980. His mathematics research has concentrated primarily on the ideal theory of Noetherian rings and Krull rings, and the algebra of polynomials and power series over commutative rings.

His service as chair of mathematics from 1981 to 1986 focused his attention on the need to support mathematics across the state of Kentucky. This led to the research and development work in mathematics distance learning and instructional technology that are the primary focus of the UK Mathematical Sciences Computing Facility which he has directed since 1990. He has, since 2002, been the principal investigator for the Appalachian Mathematics and Science Partnership, an NSF-sponsored partnership of ten colleges and universities and 60 school districts which is dedicated to improving math and science teaching and learning in eastern Kentucky, northern Tennessee, western Virginia, and western West Virginia. When he has time, he enjoys restoring 1960's vintage cars, particularly Mustangs and MG's.

Allan Feldman

Allan Feldman is Professor of Science Education and Teacher Education at the University of Massachusetts Amherst. For the past 20 years his research has focused on science teacher learning and action research. Recently he has begun to study the ways in which people learn to become science researchers in apprenticeship situations. He has been PI and co-PI of numerous NSF projects, many of which have been in collaboration with colleagues in the sciences and engineering. In addition to his research activities, he teaches and advises preservice teachers and doctoral students. He is the director of the Pioneer Valley STEM Network, which is a collaboration of colleges, school districts, museums and other non-profit groups, and industry. He is also the Associate Director of the STEM Education Institute. He taught middle and high school science and math for 17 years before obtaining his doctorate at Stanford University.

Bert Flugman

Bert Flugman is the Director of the Center for Advanced Study in Education (CASE) and a member of the Ph.D. Program in Educational Psychology at the Graduate Center, of the City University of New York. CASE conducts basic and applied research concerned with improving and upgrading the quality of education in urban areas. CASE serves as a forum for consideration of policy issues, as a center for interdisciplinary approaches to educational problems, and as a clearinghouse in areas of educational research.

As Director of CASE, Professor Flugman has supervised the development and implementation of hundreds of R&D projects. In addition, he has been actively involved as a researcher in the evaluations of such projects as: A Program to Create Systemic Change in Math and Science Education in New York City; The New York City Collaborative for Excellence in Teacher Preparation in Mathematics, Science and Technology; The Northeast Regional Technology in Education Consortium to Support Instructional Technology in Schools; The CUNY Consortium for Effective Leadership School Principal Development Program; The Use of Computer Assisted Guidance and Information Systems in New York City Schools; A Science Museum's Contribution to the Preparation of Science Teachers (the CLUSTER Model) and Mathematics Across the Middle School Mathematics, Science and Technology Curriculum (MSTP).

Allan Gerstenlauer

Dr. Allan Gerstenlauer has served the Longwood School District as a teacher and administrator for 35 years, the past four as the Superintendent of Schools. He began his career as a high school social studies teacher before becoming a building administrator, and later, the Assistant Superintendent for Instruction and Learning. It was in that position he first became active in the MSTP project as a way to improve mathematics instruction and student performance in the district. In 2005 he was named as a co-Principal Investigator for the project. Longwood is a suburban school district on Long Island, NY, that serves a diverse student population of approximately 9,500. The district is located in Middle Island in central Suffolk County.

Michael Hacker

Michael Hacker is Co-director of the Center for Technological Literacy at Hofstra University. He formerly served as a classroom teacher, department supervisor, and university teacher educator. As the New York State Education Department (NYSED) Supervisor for Technology Education, he co-managed the development of the New York State Standards for Mathematics, Science, and Technology, and led the development and implementation of innovative middle and high school curricula that now serve as national models. For over 40 years, technology education has been at the core of his professional life and he has co-directed ten large-scale National Science Foundation (NSF) projects that advance K-14 STEM education.

Mr. Hacker attended public schools in New York City, was graduated from Stuyvesant High School, received his Bachelors and Masters degrees and administrative certification from the City College of New York, and pursued Doctoral studies at New York University. He is a member of the International Technology Education Association (ITEA) Academy of Fellows, received the Epsilon Pi Tau Distinguished Service Citation; the ITEA Award of Distinction, and State Supervisor of the Year award; and the Institute of Electronics and Electrical Engineers Mathematics and Science Education Award.

Mr. Hacker has authored five secondary school textbooks, numerous journal articles, and contributed to and edited national and international conference proceedings. He has been a consultant to the American Association for the Advancement of Science, the British Technology Enhancement Project, and to various state education departments and technology education professional organizations. He has served repeatedly as an NSF expert panel reviewer, and has directed several international NATO-sponsored conferences focused on technological education. He was a member of the writing team for the NSF-funded national *Standards for Technological Literacy*.

Mark Hardy

Mark W. Hardy is an Assistant Professor in the Department of Technology at the State University of New York at Oswego. Dr. Hardy teaches technology education undergraduate laboratory courses and graduate education courses at Oswego. He holds a Ph.D. in Computing Technology in Education from Nova Southeastern University. His research interests include the use of simulations for laboratory instruction and the integration of mathematics and science into technology education laboratory instruction.

Sandra H. Harpole

Dr. Sandra H. Harpole is a graduate of Mississippi State University with a B.S in 1971, M.Ed. in 1983 and a doctorate in education in 1986. She taught chemistry and physics at West Point High School from 1971-1987 and has been a member of the faculty at Mississippi State University since 1987. Among the honors Dr. Harpole has received are the Presidential Award for Excellence in Science Teaching, the John Grisham Master Teacher Award, the Mississippi Science Teachers Association Outstanding College Science Teacher Award, the Faculty Achievement Award for her contributions in service, Outstanding Faculty Woman at Mississippi State University twice, and a Distinguished Service Citation from the American Association of Physics Teachers.

She was recently recognized as a Dynamic Woman of Mississippi and as a member of the class of 2008 Top Fifty Business Women in Mississippi. She has received numerous state and national research grants for teacher enhancement and training in science, mathematics and technology. She currently directs grants with awards totaling $10,000,000 and serves as co-principal investigator on two additional National Science Foundation grants totaling over $875,000. She is principal investigator and director for Mississippi NSF EPSCoR. Included in her professional and academic association memberships are the Phi Kappa Phi, Sigma Xi, American Association of Physics Teachers, Delta Kappa Gamma and Golden Key Honor Society. She is a member of the United States Golf Association Women's Mid-Amateur Committee and served as the general chair of the USGA 2006 Women's Mid-Amateur Championship conducted at Old Waverly Golf Club in West Point, MS, October 19-26, 2006. She and her husband, Martin Harpole, have a daughter, Beth Proffitt (an MSU graduate) and three grandchildren who are residents of Columbus.

Deborah Hecht

Dr. Deborah Hecht is a Project Director at the Center for Advanced Study in Education (CASE) at the Graduate Center, of the City University of New York. Dr. Hecht has lead numerous research, evaluation, and development projects in the areas of educational reform, and has a particular interest in the areas of STEM and applied learning. She is particularly interested in the ways in which schools can create sustainable change and ways of empowering youth and teachers as agents of change. Dr. Hecht conducts both quantitative and qualitative research in K-16 settings. She is a lead evaluator on the MSTP Project.

Maria Hoepfl

Dr. Marie Hoepfl is Professor and Graduate Program Director in the Department of Technology at Appalachian State University. She holds degrees in Industrial Education, Education Administration, and Technology Education. She taught at the middle and high school levels for six years, and has taught at the university level since 1994.

Dr. Hoepfl served as a program officer at the National Science Foundation in 2001-2002, was a three-term member of the executive board of the Council on Technology Teacher Education, and edited volumes 38-39 of the *Journal of Industrial Teacher Education (JITE)*. She co-edited the 2007 CTTE Yearbook titled *Assessment of Technology Education,* and currently serves on the editorial review boards of *The Technology Teacher,* the *Journal of Industrial Teacher Education,* the *International Journal of Technology and Design Education,* and the *JITE.* Dr. Hoepfl has published a number of articles and chapters on technology education research, curriculum, and assessment.

Michael Jabot

Michael Jabot is Professor of Physics and Science Education at the State University of New York at Fredonia. He has been engaged in research and development activities related to the development of thinking and problem-solving abilities of students, the assessment of subject matter learning, and the integration of cognitive science and educational measurement. His most recent work has focused on the uses of technology and media in creating meaningful learning and instructional environments investigating how teachers interpret and implement curricula, including teacher knowledge, beliefs and goals and differences in the materials themselves (e.g., technology-intensive vs paper-based).

His funded research includes grants from the National Science Foundation to investigate the impact of inquiry-based methods in science instruction; the US Department of Education to implement a knowledge portal for teacher professional development, and grants to explore applications of emerging technologies on classroom learning in mathematics and science. Jabot also serves on the National Faculty of the Smithsonian Institution as part of their *LASER* initiative as well as serving on a large number of national committees focused on STEM issues.

Craig Kesselheim

Craig Kesselheim was a senior consultant for Great Maine Schools Project at the Senator George J. Mitchell Scholarship Research Institute from 2004-2007 and is now senior associate with the Great Schools Partnership. In addition to working as a coach and technical consultant to schools across northern Maine, Craig is the director of the Southern Aroostook Math Science Partnership, a grant-funded initiative to strengthen math and science instruction in three rural middle/high schools, one regional technical center, and the science and math faculty of Northern Maine

Community College in Presque Isle. He is also an experienced Professional Learning Community trainer and facilitator, and has led seminars for schools in Colorado, New York, and Maine.

Prior to joining the Great Schools Partnership, Craig was a middle school science teacher in Wyoming and the director of education at the Teton Science School. In the schools of Mount Desert Island, Maine, he served as a K-12 curriculum coordinator, a K-8 principal, and a science facilitator for the Maine Mathematics and Science Alliance. After earning a doctorate in science education from the University of Maine, Craig was assistant professor of biology and science education at the University of Central Arkansas before returning to Maine with his family. He also has a BA from College of the Atlantic and an MAT from Bridgewater State College. Craig is currently completing an appointment on the National Academy of Engineering's K-12 Engineering Education Committee.

Janet Kolodner

Janet Kolodner is a Regents' Professor in the School of Interactive Computing at Georgia Institute of Technology. Her research, for the past 30 years, has addressed a wide variety of issues in learning, memory, and problem solving, both in computers and in people. During the 1980's, she pioneered the computer method called case-based reasoning, which allows a computer to reason and learn from its experiences. The first case-based design aids (CBDA'S) also came from her lab. Archie-2, for example, helped architecture students with conceptual design. During the early 1990's, she used the cognitive model implied by case-based reasoning to address issues in creative design. JULIA planned meals, Creative JULIA figured out what to do with leftover rice, IMPROVISOR did simple mechanical design, and ALEC simulated Alexander Graham Bell in his invention of the telephone. Later in the 1990's she used case-based reasoning's cognitive model to guide design of science curriculum for middle school. Learning by Design™ is a design-based learning approach and an inquiry-oriented project-based approach to science learning that has children learn science from their design experiences. The sequencing of activities in the classroom encourages students to reflect on their design and science experiences in ways that CBR says are appropriate for integrating them well into memory. LBD curriculum units and the sequencing structures in LBD are being integrated into a full 3-year middle-school science curriculum called Project-Based Inquiry Science (PBIS), to be published in time for use in the 2008-2009 academic year.

Most recently, Kolodner's research uses what she learned in designing LBD to create informal learning environments to help middle schoolers come to think of themselves as competent scientific reasoners. In Kitchen Science Investigators, children learn science in the context of cooking. In Hovering Around, they learn about motion and forces, about airflow, and how to explain in the context of designing hovercraft. Kolodner is founding Editor in Chief of the Journal of the Learning Sciences and a founder and first Executive Officer of the International Society for the Learning Sciences. She has headed up the Cognitive Science Program at Georgia Tech and headed an organization called EduTech in the mid-90's whose mission was to use what we know about cognition to design educational software and integrate it appropriately into educational environments.

Glenda Lappan

Glenda Lappan, University Distinguished Professor, Department of Mathematics, Michigan State University, received her Doctoral Degree in Mathematics and Education from the University of Georgia in 1965 and since has been at Michigan State University. Her research and development interests are in the connected areas of students' learning of mathematics and mathematics teacher professional growth and change at the middle and secondary levels. From 1989–91 she was on leave to serve as the Program Director for Teacher Preparation at the National Science Foundation. From 1997–2001 she was on leave to serve as President of the National Council of Teachers of Mathematics. She has published over a hundred scholarly papers.
She is currently the Co-Director of the Connected Mathematics Project *2*, which was funded by the National Science Foundation to develop a second iteration of CMP *1*, a complete middle school mathematics curriculum for teachers and for students. She served as the Chair of the grades 5–8 writing group for the National Council of Teachers of Mathematics' (NCTM*) Curriculum and Evaluation Standards for School Mathematics* (1989), and as Chair of the Commission that developed the NCTM *Professional Standards for Teaching Mathematics* (1991). She served as President of NCTM during the development and release of the 2001 *NCTM Principles and Standards for School Mathematics*. In 1996, she was appointed by the Secretary of Education to the National Education Research Policy and Priorities Board on which she served for 9 years.

From 1997–1999 she served on the Advisory Board for Education and Human Resources at the National Science Foundation. She served as the Vice Chair of the Mathematical Science Education Board of the National Research Council for five years and the Chair of the Conference Board of the Mathematical Sciences for two years. In the '90s she received a University Distinguished Faculty Award from Michigan State University, the Michigan Council of Teachers of Mathematics Lifetime Achievement Award, the Association of Women in Mathematics Louise Hay Award for outstanding contributions to Mathematics Education, the Meritorious Faculty award from the College of Natural Science Alumni Association at Michigan State University. In 2001 she received the George Eastman Medal for Excellence from the University of Rochester. In 2006 she was honored with the Glenn Gilbert Award by the National Council of Supervisors of Mathematics and was given the Outstanding Alumni Award by the University of Georgia. In 2007 she, with her colleague Elizabeth Phillips, received the Outstanding Curriculum Design Award from the International Society for Design and Development in Education.

Richard Lehrer

Richard Lehrer is professor of science education at Vanderbilt University. A former high school science teacher, he received a Ph.D. in educational psychology and statistics from the University of New York, Albany and a B.S. in Biology from Rensselaer Polytechnic Institute. His research focuses on classroom practices that support the growth and development of model-based reasoning in mathematics and in science. His interests include the role of inscription and notation in the growth of reasoning, education as a design profession, and the development of methods and measures appropriate for the study of learning in complex systems, such as classrooms and schools. He is co-editor of *Cognition and Instruction* and has served on several NRC committees, including one currently examining engineering education, K-12.

W. James Lewis

W. James "Jim" Lewis is a professor of mathematics and Director of the Center for Science, Mathematics, and Computer Education at the University of Nebraska-Lincoln. Previously, he served as chair of the Department of Mathematics for 15 years. He is an award winning teacher and an elected member of UNL's Academy of Distinguished Teachers. He also has received awards from the UNL Chancellor's Commission on the Status of Women and the Lincoln-Lancaster County Women's Commission for his support of opportunities for women in the mathematical sciences. He was a co-PI for the Nebraska Math and Science Initiative, Nebraska's NSF-funded SSI and for Math Matters, a NSF grant to revise the mathematics education of future elementary school teachers at UNL. Currently, he is lead PI for Math in the Middle Institute Partnership, an NSF-funded Math Science Partnership and for the Targeted MSP Partnership, Nebraska MATH. He is a member of the National Research Council's Committee on Teacher Preparation Programs in the United States. He was chair of the Steering Committee that produced the CBMS report, *The Mathematical Education of Teachers*, co-chair of the NRC committee that produced *Educating Teachers of Science, Mathematics and Technology: New Practices for the new Millennium*. He was a member of the AMS Task Force that produced *Towards Excellence: Leading a Doctoral Mathematics Department in the 21st Century*. He received his Ph.D. in mathematics from Louisiana State University.

Marcia C. Linn

Marcia C. Linn is professor of development and cognition specializing in education in mathematics, science, and technology in the Graduate School of Education at the University of California, Berkeley. She is a member of the National Academy of Education and a Fellow of the American Association for the Advancement of Science, the American Psychological Association, and Association for Psychological Science. She has served as Chair of the AAAS Education Section and as President of the International Society of the Learning Sciences. She directs the NSF-funded Technology enhanced Learning in Science (TELS) center. Board service includes the American Association for the Advancement of Science board, the Graduate Record Examination Board of the Educational Testing Service, the McDonnell Foundation Cognitive Studies in Education Practice board, and the Education and Human Resources Directorate at the National Science Foundation. She has twice been a fellow at the Center for Advanced Study in Behavioral Sciences.

Her books include *Computers, Teachers, Peers* (2000), *Internet Environments for Science Education* (2004) and *Designing Coherent Science Education* (2008). She chairs the Technology, Education—Connections (TEC) series for Teachers College Press. Awards include the National Association for Research in Science Teaching Award for Lifelong Distinguished Contributions to Science Education, the American Educational Research Association: Willystine Goodsell Award, and the Council of Scientific Society Presidents first award for Excellence in Educational Research. http://tels.berkeley.edu/~mclinn/

Michal Lomask

Dr. Michal Lomask holds a graduate degree in Biochemistry and a Ph.D. in science education, both from the Technion, Israel Institute of Technology. Since 1990, Dr. Lomask has been working for the Connecticut State Department of Education, as a science education consultant. In this capacity she has overseen the development of CT science curriculum framework, student assessments and teacher induction programs. Her research interests are focused on the use of performance-based assessment for the support and evaluation of both teachers.

Scott McMullen

Scott McMullen is the District Coordinator for Science and Technology Education in the Manhasset School District on Long Island, New York. He has been in public education for thirty-five years. The most recent 22 years have been as a K-12 science administrator. Before that, Mr. McMullen was a high school department chairperson and a high school science teacher. He has taught middle school science, high school science, and in a science teacher preparation program at a local university. Participation in school district, county, regional, and state initiatives of note include alternative assessment projects, MSTe (NSF supported Mathematics, Science, and Technology in Elementary Schools), and serving as a K-8 New York State mentor and science assessment liaison. Recent professional development has included workshops in educational technology and AAAS's Using the *Atlas of Science Literacy*.

He has lead workshops on elementary science topics, problem solving, and the integration of mathematics, science, and technology in elementary and middle schools. Conference presentations have occurred regionally, in New York State, and in Africa on topics including early childhood science, assessments, constructivism, supervision, technology, and New York State standards, core curricula, and assessments. Mr. McMullen has a BS and MA in Biology from State University of New York at Stony Brook. Graduate science research focused on animal behavior. Administrative certification was earned at Long Island University/CW Post.

Ramakrishnan Menon

Ramakrishnan Menon, Chair & Professor, Math Education, Division of Curriculululm & Instruction, Charter College of Education, California State University Los Angeles. Believing in lifelong learning, my academic qualifications include the following: PhD (UBC, Canada), MA (UNI, USA), Grad. Dip. of Arts in Language Studies (WACAE, Australia), BA (UM, Malaya), BS (Univ. London, England), Dip. Ed. (Univ. London, England), Cert in Basic Systems Analysis (NCC, Malaysia), and Teaching Cert (MTC, Malaysia).

My main interest is to conduct research that affects practice. Hence, I have conducted (and am conducting) professional development courses for practicing teachers, at the elementary, middle, and high school levels. These include Connected Math workshops, Texas Instruments workshops, Eisenhower grant for professional development of teachers, algebra workshops for math teachers in Singapore, for CSULA graduate assistants teaching algebra, for undergraduate tutors of high school math students through the GEAR Up grant, for math teachers in Los Angeles through the CTEI grant, and for math teachers in Egypt through the USAID grant. I am currently working on an NSF grant for a Math and Science Partnership (MSP) project (deadline for grant submission is February 2009) with colleagues in the Math Department, the Biological Sciences, and a local school district, to investigate the impact of integrating innovative pedagogical approaches to high school algebra that include applications to environmental science. I am also interested in exploring subject matter knowledge of math teachers, the connections between math and language, as well as assessing students' math proficiency.

I have taught Math, AP Math courses, Science, Physics, and English in middle schools and high schools and math ed related courses to preservice and inservice teachers in various countries (Australia, Canada, Egypt, Malaysia, Singapore and the United States) since 1974. I have also taught research methodology courses (including Statistics), and advised/supervised about 150 graduate students, both Master's and Doctoral, and been Chair/on the Thesis Committee, as well as been an external Examiner of doctoral theses from Australia and Malaysia. I have supervised more than 350 student teachers (both elementary and secondary school) and been a reviewer for many professional journals, conducted classroom based research on math and teacher education, presented papers at more than 100 scholarly meetings, published more than 50 scholarly papers, and have participated in more than 50 professional development workshops/seminars. I have also taught computer education courses, and run online courses (WebCT) for preservice and inservice teachers, including online mentoring. (Please refer to my Faculty webpage for a brief account of myself, at http://www.calstatela.edu/faculty/rmenon/).

Mitchell Nathan

Dr. Mitchell Nathan is Professor of Educational Psychology at the University of Wisconsin-Madison, where he is Chair of the Learning Sciences program. He holds appointments in Curriculum and Instruction, the Psychology Department, the Wisconsin Center for Educational Research, and the Center on Education and Work.

Dr. Nathan received his PhD in experimental (cognitive) psychology from the University of Colorado at Boulder. He holds a B.S. in electrical and computer engineering, mathematics and history from Carnegie Mellon University. As an engineer, Dr. Nathan worked in research and development in artificial intelligence and expert systems, computer vision and robotic systems mobility. This work inspired an interest in how people represent their knowledge of the physical and conceptual realms.

Dr. Nathan's research is largely rooted in cognitive, embodied and social perspectives on learning and instruction, and employs quantitative and qualitative methods. Currently, he examines the intersection of student and teacher cognition as it plays out in classroom learning situations, primarily involving middle and high school mathematics, science and engineering. His research on students' reasoning showed that they may invent effective strategies and representations for solving math problems, and these methods can serve as bridges for instruction. He is also exploring the embodied nature of students' knowledge, as exhibited by gestures, and the mediating effects of action on conceptual knowledge. His studies of teachers' beliefs about the development of students' mathematical reasoning showed that content experts can show evidence of expert blind spot, which influences teachers' expectations of what makes things difficult for their students.

He is currently co-principal investigator for the AWAKEN Project (funded by NSF-EEP), which examines the nature of high school pre-engineering, early college engineering, and professional engineering practice in order to foster a more diverse and more able pool of engineering students and practitioners.

Greg Pearson

Greg Pearson is a Senior Program Officer with the National Academy of Engineering (NAE) in Washington, D.C. In that role, he develops and manages new areas of activity within the NAE Program Office related to K-12 engineering education, technological literacy, and the public understanding of engineering. Greg currently serves as the responsible staff officer for two projects: "Understanding and Improving K-12 Engineering in the United States" and "Exploring Content Standards for Engineering Education in K-12." He was the study director for an NSF-funded project that resulted in the 2008 publication of *Changing the Conversation: Messages for Improving Public Understanding of Engineering* and was co-editor of the reports *Tech Tally: Approaches to Assessing Technological Literacy* (2006) and *Technically Speaking: Why All Americans Need to Know More About Technology* (2002).

In the late 1990s, Greg oversaw NAE and National Research Council reviews of technology education content standards developed by the International Technology Education Association. He works collaboratively with colleagues within and outside the National Academies on a variety of projects involving K-12 science, mathematics, technology, and engineering education, and the public understanding of engineering and science. Greg has an undergraduate degree in biology from Swarthmore College and a graduate degree in journalism from The American University.

Theodora Pinou

Theodora Pinou is an Assistant Professor in the Department of Biological and Environmental Sciences and the Secondary Science Education Coordinator at Western Connecticut State University. Pinou prepares secondary science education students in the integration of research and pedagogy, as a mechanism for strengthening student engagement in the sciences. Pinou's research programs are international and link scholars and educators in Latin America and Europe with scholars and educators in Connecticut, thus helping to bridge best practices in teaching and learning among cultural groups and promote sustainability.

Pinou's research in interspecies relationships offers students opportunities to discover new species from poorly studied tropical/marine environments and build close working relationships with leading scholars in the molecular sciences, collection management, and environmental sciences. It also provides social science students with opportunities to study human impact on the environment, and think about the responsibility humans have in balancing the goals of resource conservation with sustainable development. Through Pinou's collaborative relationship with private companies and landowners students have authentic experiences and future employment opportunities, as well as international exchange experiences.

Gerhard L. Salinger

Gerhard Salinger is a Program Director in the Division of Research on Learning in Formal and Informal Settings in the Directorate for Education and Human Resources at the National Science Foundation (NSF). In this position, he recommends the funding of proposals to develop nationally disseminated instructional materials and professional development models supporting educational reform in mathematics, science and technology education in K-12 classrooms. He is also co-Lead Program Director of the Advanced Technological Education program since inception in 1993. This program supports technician education at the two-year college level and preparation for that at the secondary schools.

Prior to coming to the NSF in 1989, Salinger was a professor in the Physics Department at Rensselaer Polytechnic Institute in Troy, New York for twenty-five years and chairman of the Department for eleven years. In his research work on the low temperature properties of amorphous materials, he supervised ten students in their Ph.D. work and has about twenty-five publications including a successful, college-level textbook on thermodynamics published by Addison-Wesley.

Salinger received his B.S. in Physics from Yale University in 1956 and an M.S. and Ph.D. in physics from the University of Illinois in 1958 and 1961 respectively. Before going to Rensselaer Polytechnic Institute in 1964, he spent two years establishing a low temperature physics laboratory at the University of Sao Paulo in Brazil.

Mark Sanders

Mark Sanders is Professor & Program Leader of Virginia Tech's Technology Education Program, and their unique *Integrative STEM Education Graduate Program*. Integrative STEM Education has been a focus of his work since serving as Co-PI of the *Technology, Science, Mathematics Integration Project* (NSF, 1991-1996). From that work, he coauthored the *TSM Connection Activities* (1996, Glencoe/McGraw-Hill), recently updated / republished as *Engineering & Design Applications* (2008, McGraw-Hill).

Sanders began his career as a high school Technology teacher in upstate New York. He earned his PhD in Education at the University of Maryland, and joined the Virginia Tech faculty in 1980. His early years at Virginia Tech focused on teaching, research, and service in the emerging curriculum area known as "communication technology," authoring a widely used textbook, *Communication Technology* (Glencoe/McGraw-Hill, 1991, 1996) and many other publications in that area. He was founding editor (1989- 1997) of the *Journal of Technology Education (JTE)* and an electronic publishing pioneer, establishing the e-version of the *JTE* in 1992—a year *before* the Web existed.

Similarly, he established and directed (1996-2009) GRAPHIC COMM CENTRAL, one of the earliest Web portals in education. He has published extensively in the area of integrative STEM Education and has held national leadership positions with the ASEE's *K-12 Engineering Education Division*, the *International Graphic Arts Education Association* (President), and the *Council on Technology Teacher Education* (Vice President). The Integrative STEM Education Program he envisioned and later (2005) co-founded offers a unique core of (face-toface and Web-based) integrative STEM Education graduate classes and degrees (Certificate, MAED, EdS, EdD and PhD) that prepare K-16 STEM education leaders, scholars, and researchers in new and integrative approaches to STEM Education.

William H. Schmidt

William H. Schmidt received his undergraduate degree in mathematics from Concordia College in River Forrest, IL and his Ph.D. from the University of Chicago in psychometrics and applied statistics. He carries the title of *University Distinguished Professor* at Michigan State University and is currently co director of the Education Policy Center, co director of the US China Center for Research and co director of the NSF PROM/SE project and holds faculty appointments in the Departments of Educational Psychology and Statistics. Previously he served as National Research Coordinator and Executive Director of the US National Center which oversaw participation of the United States in the IEA sponsored Third International Mathematics and Science Study (TIMSS). He has published in numerous journals including the Journal of the American Statistical Association, Journal of Educational Statistics, and the Journal of Educational Measurement.

He has co-authored seven books including Why Schools Matter. His current writing and research concerns issues of academic content in K-12 schooling, assessment theory and the effects of curriculum on academic achievement. He is also concerned with educational policy related to mathematics, science and testing in general. He was awarded the Honorary Doctorate Degree at Concordia University in 1997 and received the1998 Willard Jacobson Lectureship from The New York Academy of Sciences and is a member of the National Academy of Education.

Christian Schunn

Christian Schunn received his PhD in Cognitive Psychology from Carnegie Mellon in 1995. He is now a Research Scientist at the Learning Research and Development Center and an Associate Professor of Psychology, Learning Sciences and Policy, and Intelligent Systems at the University of Pittsburgh. From 2003 to 2006, he co-directed a $35M NSF-funded center aimed at improving math and science education K-12 in urban settings, and currently co-directs the IES-funded Center and Cognition and Science Education.
He currently is a member of an NRC panel on K-12 Engineering Education, reflecting his research on the cognitive basis of engineering innovation and creativity and his educational research and curriculum design work on the use of engineering design projects to teach science and mathematics. He continues to direct the SWoRD project, a web-based system for using peer-review to bring writing back into the undergraduate curriculum and to provide a supercollider for educational research on writing. He has received over 25 external grants and has published over 60 journal papers, books, and book chapters on a wide variety of topics at the intersection of cognitive science and educational application, in domain areas as diverse as army leadership, football coaching, weather forecasting, astronomy, submarine navigation, and engineering design.

Kendall N. Starkweather

Dr. Kendall N. Starkweather is Executive Director/CEO of the International Technology Education Association (ITEA) located in Reston, Virginia. His background includes experience as a high school teacher and as a tenured graduate faculty member at the College of Education, University of Maryland. He is the publisher of the association's journals, *The Technology Teacher* and *Technology and Children*, which contain curriculum and instructional materials dealing with technology and engineering at the K-12 level. He has led the association during the development of ITEA's Standards for Technological Literacy, standards for program, assessment, and professional development, and related curriculum work that have been translated into six languages. He has spoken on the topic of technological literacy in most states and provinces in North America, and has spoken or consulted in Australia, Canada, England, Greece, the Netherlands, Japan, New Zealand, and Taiwan.

Gay B. Stewart

Dr. Gay Stewart received her Ph.D. in physics from the University of Illinois, Urbana- Champaign in 1994. While her thesis research was in experimental high energy physics, she was also concurrently involved with physics education reform. Her involvement began formally with her attendance at the Workshop Physics Conference at Dickinson College in 1993. Upon receiving her Ph.D., as a mother of two, she shifted her research purely to the condition of science education in the United States. In May, 1995 her work gained its first NSF support through a DUE Course and Curriculum Development grant.

She is firmly committed to improving physics education and is involved at a variety of levels. She has given numerous invited talks related to physics education at APS national meetings, as well as those of AAPT, AAC&U, and NSF/UFE. She served as the AAPT/APS liaison on the APS Forum on Education Executive Committee, and later as its chair. She is now an APS councilor. She serves on the board of a science education research journal. She is a member of the Project Kaleidoscope Faculty for the 21st Century, and their Physics Task Force. She is chair of the College Board's Science Academic Advisory Committee, and is a member of their Academic Assembly Council. She was a co-chair of the Advanced Placement physics redesign commission, and is a member of the new Curriculum Development and Assessment Committee. She served as chair of the undergraduate affairs committee for her department during a transitional time, which saw the average number of graduating majors in physics increase by a factor of five in four years. She is teaching assistant mentor, and developed a TA preparation program based in part on the University of Minnesota FIPSE-supported project. This program grew into one of four pilot sites in physics for the NSF/AAPT "Shaping the Preparation of Future Science Faculty."

She directed a primary institution for the AIP/APS/AAPT "Physics Teachers Education Coalition" (PTEC) and serves on the steering committee guiding the formation of the constantly growing community of over 100 PTEC member departments, which have expressed a commitment to improving the preparation of future physics and physical science teachers. She is the Regional Coordinator for Arkansas for the AAPT/PTRA, as well as a member (PER Advisor) of the AAPT/PTRA National Advisory Board. She is co-PI of a GK-12 project that places graduate students in middle school mathematics and science classrooms. The results of that project were so favorable that getting mathematics and science teachers the opportunity to work together is a major component of the new NSF-MSP project, *College Ready in Mathematics and Physics.*

Bruce Torff

Bruce Torff is Professor of Curriculum and Teaching at Hofstra University in Hempstead, New York. He is also director and founder of Hofstra's interdisciplinary *Doctoral Program in Learning and Teaching*. An educational psychologist with expertise in research design and statistics, Mr. Torff has published on topics including teachers' beliefs and attitudes (especially concerning critical-thinking instruction and professional development), expertise in teaching, intelligence, intuitive conceptions, and musical cognition. His books include *Understanding and Teaching the Intuitive Mind* and *Multiple Intelligences and Assessment.*

Mr. Torff's work also appears in such journals as Educational Researcher, Journal of Educational Psychology, Phi Delta Kappan, Educational and Psychological Measurement, and Journal of Teacher Education. After earning a doctorate and two master's degrees at Harvard University, where he worked with Howard Gardner, Mr. Torff held a postdoctoral appointment at Yale University in collaboration with Robert J. Sternberg. He is active as a grant evaluator and provider of professional-development services for educators. Mr. Torff is also a pianist and songwriter.

Alan Tucker

Ph.D. Mathematics, Stanford, 1969. Distinguished Teaching Professor of Applied Math. & Statistics at SUNY-Stony Brook. Mr. Tucker has been at Stony Brook since 1970. Deputy Chair or Chair since 1978.

Extensive service to Math. Assoc. of America includes MAA First Vice-President, 1988-89 and Chair of MAA Education Council, 1991-96. Recipient of MAA's 1994 National Award for Distinguished Teaching of Mathematics

Mr. Tucker has been the lead author on several NSF reports about collegiate mathematics and the mathematical education of teachers, including The Mathematical Education of Teachers Conference Board of Math.

Mr. Tucker has been PI of the large NSF grant to the MAA titled, Preparing Mathematicians to Educate Teachers (PMET). Along with running dozens of workshops for mathematicians who teach future teachers, PMET has sponsored workshops where mathematicians examined key issues in K-8 mathematics.

Linda L. Walker

Linda L. Walker's experience lies in the teaching of middle school mathematics, serving as an assistant principal, and as a coach for middle school math teachers in nine schools. She was with Leon County Schools in Tallahassee, FL from 1971-2000 when she retired due to her husband's health. She began leading professional development for teachers in 1988 and continues to be active in this realm having worked with teachers in school districts in more than half of the states. She has provided professional development to support the implementation of the Connected Math Project in many school districts. She authored five supplementary math texts published by the Florida Department of Education and serves as the math consultant on the FCAT Explorer

Program serving Florida students in grades 3-11 on the internet. She has served on editorial panels for two NCTM journals and for one NCTM Yearbook as well as on the MATHCOUNTS Committee and a program committee for an annual NCTM meeting.

Iris R. Weiss

Iris R. Weiss is President of Horizon Research, Inc. (HRI), a contract research firm in Chapel Hill, NC specializing in mathematics and science education research and evaluation. She has had extensive experience in survey design and analysis and in mathematics and science education, evaluation, and policy research. Dr. Weiss received a Bachelor's Degree in Biology from Cornell University, a Master's Degree in Science Education from Harvard University, and a Ph.D. in Curriculum and Instruction from the University of North Carolina at Chapel Hill. Before establishing HRI in 1987, Dr. Weiss was Senior Educational Research Scientist at the Research Triangle Institute. She participated in the evaluation of NSF's model middle school mathematics and science teacher preparation and Triad curriculum programs; served on the assessment working group for the National Standards of Science Education; directed a series of national surveys of mathematics and science education; and coordinated the Inside the Classroom national observation study; and served as Principal Investigator for several studies of systemic reform, including the cross-site evaluation of the Local Systemic Change professional development program.

Dr. Weiss is currently Principal Investigator of a Knowledge Management and Dissemination project for NSF's Math Science Partnership program, and co-PI of the Center for the Study of Mathematics Curriculum. She is particularly interested in ways to accelerate the accumulation and application of knowledge, including establishing consensus standards of evidence and documentation for research and evaluation studies, and mechanisms for focusing research more extensively and coherently on key problems of practice.

Kenneth D. Welty

Kenneth Welty is a Professor in the School of Education at the University of Wisconsin- Stout. He teaches a variety of undergraduate and graduate course in curriculum development, instructional methodology, and student assessment. He received his Bachelor's and Master's degrees from Illinois State University and earned his Doctor of Philosophy degree from the University of Illinois at Champaign/Urbana. Prior to joining the faculty at UW-Stout, he was a Visiting Professor in the College of Education at the University of Illinois, a Research Associate at Illinois State University, and a technology education teacher at Central Catholic High School in Bloomington, Illinois. His recent work includes a descriptive study of K-12 curricula for the National Academy of Engineering. The study examined 20 curriculum initiatives for their treatment of engineering concepts; including design, analysis, modeling, systems, and constraints; and their inclusion of mathematics, science, and technology content.

Arthur L. White

Arthur L. White holds a BS in secondary science and mathematics education from the University of Northern Colorado, a MBS in secondary education from University of Colorado, and a PhD in secondary education with emphases in science and research and evaluation from the University of Colorado. He has taught at the secondary school level and has taught courses in science and mathematics education for middle school and secondary preservice and inservice teachers at The Ohio State University for 39 years. In addition, Dr. White served as the Mathematics, Science, and Technology Education Program Coordinator.

Dr. White's research interests include science education, the integration of science and mathematics education, action research, the use of technology in the teaching and learning of science and mathematics, and the connections between research and evaluation to practice in the classroom. Dr. White is internationally recognized for his work in the area of the integration of science and mathematics education. He has published in both science and mathematics journals and books and has been invited to present papers at conferences and universities in 25 countries.

Dr. White has been actively involved in both the science and mathematics community. He served as a Co-Principal Investigator for The National Center for Science Teaching and Learning, Research Coordinator for the National Association for Research in Science Teaching, Executive Director for the National Association for Research in Science Teaching, Executive Director for the School Science and Mathematics Association, and President of the School Science and Mathematics Association. He was Co-Principal Investigator for the influential National Science Foundation/School Science and Mathematics Association Wingspread Conference: A Network for Integrated Science and Mathematics Teaching and Learning. Also, he has served as an external evaluator and a consultant for numerous mathematics and/or science grants supported by the National Science Foundation and the Department of Education.

Sharon Whitton

Sharon Whitton, Ph.D. is the Director of graduate programs in Mathematics Education at Hofstra University. She has coordinated the mathematics components of NSF STEM projects (MSTP, MSTe, and LIMM) for more than 15 years. These projects have targeted professional development for STEM teachers spanning grades K-12. Her experience in mathematics teaching and teacher education is extensive. As a college professor for more than 30 years, she teaches mathematics, computing, and mathematics education. She has also chaired the departments of Curriculum and Teaching at two different universities.

Prior to becoming a college professor, she served as mathematics teacher and Department Chair at the high school level. She currently serves as co-PI of Hofstra's MSTP project and has recently submitted another proposal to NSF to extend many of the features of this middle-school project into the high school level. If funded, this project will be titled, "Exploring Teacher Enhancement for Advanced Mathematics, (ETEAM)." Additionally, Dr. Whitton was recently designated as a PI for a related project proposal, "Virtual Environments for Problem-Based Learning (VEPBL)," a computer based project targeting contextual learning for college students. That proposal, which lists Hofstra University as a collaborating partner, was recently submitted to the National Priorities Research Program of the Qatar National Research Fund. Dr. Whitton's primary areas of research include: cyber-enabled mathematics instruction, student-centered contextual learning, and teaching for understanding.

Jennifer Wilhelm

Jennifer Wilhelm is an Associate Professor in the program area of Science and Mathematics Education. She holds an M.S. in Physics from Michigan State University and a Ph.D. in Mathematics/Science Education from the University of Texas at Austin. She joined the faculty of Texas Tech University in 2002. She is currently the Program Coordinator for the Science and Mathematics Education Program. Dr. Jennifer Wilhelm's primary research interest involves the design of inquiry-based, projectenhanced, interdisciplinary learning environments. Dr. Wilhelm investigates how people understand science and mathematics concepts as they participate in project work that demands the integration of multiple content areas.

Dr. Wilhelm's research focuses on project pieces that are inherently interdisciplinary and fruitful for contextualized student learning. Some examples include examining the development of students' science and mathematics content understanding as they engage in studies of motion and rate of change; sound waves and trigonometry; and the moon's phases, the moon's motion, and spatial geometry.

Karen Zuga

Professor Karen Zuga has recently retired from The Ohio State University where she was a member of the STEM faculty in the School of Teaching and Learning. Her subject specialty is technology education with an emphasis on the history, philosophy, curriculum, and research of the field. She has had a long standing interest in STEM and integration via guest editing two issues of *Theory Into Practice* on the integration of MST, serving as a board member of the National Association of Science, Technology and Society, and taking an appointment as a program officer at the National Science Foundation in the Division of Research and Learning in formal and Informal Education.

She has over 60 publications in journals, other texts, and on-line dealing with technology education curriculum, integration of technology education in elementary school education, research analysis, and gender concerns. She has received funding for several grants, the most recent of which was *Technology Teacher Inservice Education* which was funded by the National Science Foundation and is available on-line. She has reviewed for five journals and has edited or guest edited for three journals. She has held leadership positions in six professional associations including one presidency, one chairperson position, and two board of directors and served a term as the section head for the Mathematics, Science, and Technology Education teacher education programs at The Ohio State University.

Karen Zuga has received over a dozen national awards for her service and scholarship, among them the Outstanding Technology Teacher Educator of the Year by the Council on Technology Teacher Education, International Technology Association Award of Distinction, Silvius/Wolansky and Council on Technology Teacher Education Author of Outstanding Publication Award, and Journal of Industrial Teacher Education Outstanding Conceptual Manuscript.

Appendix B

Pre-Conference Papers

Middle Childhood Teacher Preparation to Facilitate the Infusion of Mathematics Into the Science Classroom

Donna F. Berlin and Arthur L. White

On October 15, 1996, the State of Ohio Department of Education adopted new guidelines for teacher education and licensure. Licensure standards were developed for the broad categories of early childhood (EC), prekindergarten through grade 3; middle childhood (MC), grades 4-9; and adolescent to young adult education (AYA), grades 7-12. Colleges or universities developed programs for state approval according to learned society guidelines (e.g., National Council for Accreditation of Teacher Education, National Council of Teachers of Mathematics, National Science Teachers Association, and the National Middle School Association) and the State Board standards and curriculum models. The Ohio State University implemented the Middle Childhood Master's of Education Program for initial teacher preparation for middle childhood education (grades 4-9) in 2002. It is a 5-quarter, post-baccalaureate program resulting in a teacher license and a Master's of Education (M. Ed.). This paper describes the Middle Childhood M. Ed. Program and discusses the preparation of teachers licensed to teach mathematics and *science* and their ability to infuse mathematics into their science teaching.

Preparation of Middle Childhood Mathematics Teachers

The Middle Childhood (MC) licensure program is designed to prepare teachers in at least two of the following areas of concentration: reading and language arts, mathematics, science, and social studies. Clearly, prospective teachers who choose their areas of concentration as science and mathematics may be best prepared to infuse mathematics into their science teaching. An examination of the courses and competencies prescribed for the mathematics area of concentration may provide insight into the requisite elements to enable science teachers to infuse mathematics into science teaching. Table 1 describes the mathematics content knowledge and mathematics pedagogical knowledge competencies mandated for prospective middle childhood mathematics teachers. Courses and experiences at The Ohio State University are provided as examples that enable students to acquire these competencies. It should be noted that these competencies were derived from recommendations of the National Council of Teachers of Mathematics and additional recommendations from the State of Ohio Department of Education which appear in italics.

Table 1 *Middle Childhood Education Mathematics Content Knowledge*

7.0 MATHEMATICS PREPARATION Programs prepare prospective teachers who - 7.1.1 use a problem-solving approach to investigate and understand mathematical content;
7.2 can communicate mathematical ideas in writing and orally, using everyday and mathematical language;
7.3 can make and evaluate mathematical conjectures and arguments and validate their own mathematical thinking;
7.4 *can make connections among ideas in mathematics* and connect mathematics to other disciplines and real-world situations;
7.5, 7.1.2 use mathematical modeling to formulate and solve problems from both mathematical and everyday situations;
7.6.1 understand and apply concepts of number, number theory and number systems;

7.6.2 understand and apply numerical computational and estimation techniques and extend them to algebraic expressions;
7.6.3 understand and apply the process of measurement *and measurement applications*;
7.6.4 use geometric concepts and relationships, *including transformations*, to describe and model mathematical ideas and real-world constructs;
7.6.5 understand and apply the concepts of statistics and probability, including exploratory data analysis and *experimental probability*;
7.6.6 use algebra to describe patterns, relations, and functions and to model and solve problems;
7.6.7 understand the role of axiomatic systems in different branches of mathematics, such as algebra and geometry;
7.6.8 explore the fundamental concepts of calculus *through models, concrete examples, and use of calculators and computers*;
7.6.9 use algorithmic and recursive techniques in solving problems;
7.7 use appropriate technology *(including graphing calculators, spread sheets, and software packages)* to explore and solve mathematical problems;
7.8 have a knowledge of historical development in mathematics, including the contributions of underrepresented groups and diverse cultures.

Table 2 *Middle Childhood Education Mathematics Pedagogical Content Knowledge*

8.0 TEACHING PREPARATION **Professional Knowledge** Programs prepare prospective teachers who - 8.1 can identify and model strategies used for teaching the following strands for Middle Childhood: - problem solving - *numbers and number relations* - *geometry* - *algebra, patterns, relations, and functions* - *measurement* - *data analysis and probability* - *estimation and computation*
8.2 use calculators, computers, and other technologies as tools for teaching mathematics;
8.3 use a variety of manipulative and visual materials for exploration and development of mathematical concepts for Middle Childhood;
8.3.1 undergo the models for developing major concepts in grades K-3;
8.3.2 develop mathematical concepts and procedures through interdisciplinary settings;
Curriculum Programs prepare prospective teachers who - 8.4 use a variety of resource materials such as software, print materials, and activity files in the learning of mathematics;
8.5 select appropriate mathematical tasks that will stimulate students' development of mathematical concepts and skills;
8.6 plan mathematical tasks and activities for students who are culturally diverse, those with limited English proficiency, and those with special needs;
Instructional Management Programs prepare prospective teachers who – 8.7, 8.8 use oral and written discourse between teacher and students and among students to develop and extend students' mathematical understanding;
8.9 create a learning environment in which students feel free to take risks;
8.10.1 use various student groupings such as collaborative groups, cooperative learning, and peer teaching;
8.10.2 accommodate different learning styles such as visual, auditory, and tactile;
Professional Culture Programs prepare prospective teachers who – 8.10.3 apply knowledge of current research and national, *Ohio*, and local guidelines relating to mathematics instruction;

8.10.4 recognize the role of reflective practice, professional development, and active participation in the community of learners to their life-long growth as a teacher;
Assessment Programs prepare prospective teachers who - 8.11.1 use assessment in the classroom to monitor students' mathematical learning and to make instructional decisions;
8.11.2 use a variety of methods to assess mathematical learning, such as open-ended questions, portfolios, and performance tasks;

While course names and content differ from institution to institution, courses at The Ohio State University are provided as examples that enable students to acquire these competencies related to mathematics content knowledge and mathematics pedagogical content knowledge. (See Appendix A.) A minimum of 33 quarter hours (22 semester hours) in mathematics content plus 6 quarter hours (4 semester hours) in mathematics methods or pedagogy are required to complete the mathematics area of concentration at the middle childhood level. The total credits for the middle childhood mathematics area of concentration is 39 quarter hours (26 semester hours) in addition to the 10 quarter hours (6.67 semester hours) required as general education requirements in the category of quantitative and logical skills.

Six specific courses were developed at The Ohio State University for students enrolled in the undergraduate Middle Childhood Program in Human Ecology or the undergraduate Middle Childhood Interdisciplinary Major in the College of Arts and Sciences. Both of these undergraduate programs lead to a Bachelor's of Science and students then apply to the Master's of Education Program in the College of Education to acquire licensure and a Master's of Education.

A review of these six Middle Childhood Mathematics courses (Mathematics 105, 106, 107, 108, 109, and 111) is warranted as they clearly indicate the mathematics content knowledge required for prospective mathematics teachers in grades 4-9. These courses are taught in either the traditional lecture/recitation format or a workshop format that reflects the pedagogical format recommended for middle childhood classrooms. Mathematics 107 is only taught in a workshop format. These new courses specifically designed for prospective mathematics teachers in grade 4-9 are highly recommended; however, traditional alternatives from the Mathematics Department are listed to accommodate students from other institutions as well as returning, older students.

Mathematics 105 Fundamental Mathematics: Concepts for Teachers I (5 Credits)
Purpose of Course: To develop an appreciation of, and basic competency in, the use of analytical thought in the development of a cohesive body of useful mathematical knowledge, with special emphasis on topics encountered in elementary and middle school mathematics programs. Math 105 deals with the whole number system, integers, rational numbers, and combinatorial counting techniques.
Topics List: Problem Solving; Numbers and the Decimal System; Fractions; Addition and Subtraction; Multiplication; Multiplication of Fractions, Decimals, and Negative Numbers; Division

Mathematics 106 Fundamental Mathematics: Concepts for Teachers II (5 Credits)

Purpose of Course: To develop an appreciation of, and basic competency in, the use of analytical thought in the development of a cohesive body of useful mathematical knowledge, with special emphasis on topics encountered in elementary and middle school mathematics programs. Math 106 introduces length, area, volume, angle, Euclidean geometry, congruent and similar triangles, symmetry and rigid motion, and knowledge of general spatial skills.
Topics List: Geometry, Geometry of Motion and Change, Measurement, More About Area and Volume

Mathematics 107 Topics in Mathematics (5 Credits)
Purpose of Course: To develop an appreciation of, and basic competency in, the use of analytical thought in the development of a cohesive body of useful mathematical knowledge, with special emphasis on topics encountered in elementary and middle school mathematics programs. Math 107 deals with number theory, combinatorics, probability, early algebra, functions, graphs, sequences and series, and general mathematical skills.
Topics List: Number Theory, Combinatorial Counting, Probability, Functions and Algebra

Mathematics 108 Number and Algebraic Structures for Middle School Teachers (5 Credits)
Purpose of Course: The purpose of the course is to prepare teachers of middle school students. In particular, it intends to deepen and extend prospective teachers' content knowledge of the mathematics they will teach as well as their ability to reason with and communicate that knowledge.
Topics List: Number Systems, Addition and Subtraction, Multiplication and Division, Exponents and Roots/Logs, Combinatorial Counting, Number Theory, Divisibility, Algebraic Structures, Algebra of Matrices

Mathematics 109 Geometry and Measurement for Middle School Teachers (5 Credits)
Purpose of Course: The purpose of the course is to prepare teachers of middle school students. In particular, it intends to deepen and extend prospective teachers' content knowledge of the mathematics they will teach as well as their ability to reason with and communicate that knowledge.
Topics List: Definitions and Euclidean Postulates; Measurement; Congruence; Similarity; Coordinate Geometry; Transformations of the Plane; Transformations in Euclidean 2 and 3 Dimensional Space; Parallel Postulate, Introduction to Non-Euclidean Geometry

Mathematics 111 Concepts of Calculus for Middle School Teachers (5 Credits)
Purpose of Course: The purpose of the course is to prepare teachers of middle school students. In particular, it intends to deepen and extend prospective teachers' content knowledge of the mathematics they will teach as well as their ability to reason with and communicate that knowledge.
Topics List: Language and Notation of Rates and Accumulation, Picturing Rates and Accumulation, Informally Measuring Rate, Precisely Measuring Rate, Informally Measuring Accumulation, Precisely Measuring Accumulation, Applications of Differential Calculus, Applications of Integral Calculus

Instrument to Measure Mathematics Content Knowledge and Mathematics Pedagogical Content Knowledge Preparation for Science Teachers

It is suggested that prospective teachers for grades 4-9 who have chosen mathematics and science as their two areas of concentration and licensure represent the ideal–a middle school teacher eminently prepared to infuse mathematics into the science classroom. Clearly, the graduates of a middle school licensure program such as the one at The Ohio State University have acquired the mathematics and science content knowledge along with the mathematics and science content pedagogical knowledge to be able to appropriately and effectively infuse mathematics into the science classroom.

However, this ideal preparation is of recent vintage and not all states have middle school licensure mandating two areas of concentration and the institutions to offer these programs. Moreover, the immediate problem seems to be middle school teachers who have been prepared as generalists (elementary school teachers) with limited science and mathematics content or middle school teachers who have been prepared as one subject specialists (secondary school teachers) with mainly science content knowledge and science content pedagogical knowledge.

Therefore, we suggest prioritizing the content knowledge and pedagogical content knowledge competencies recommended for a middle childhood mathematics teacher in terms of application to and importance for the science classroom. To this end, we have developed an instrument based upon the mathematics content knowledge and mathematics pedagogical content knowledge recommended for middle childhood mathematics teachers. Related to these competencies, two dimensions are addressed: (a) Importance to the Science Teacher and (b) Preparation of the Science Teacher. The purpose of this instrument is to be able to identify critical mathematics competencies along with areas in need of preparation for current middle school science teachers to advance the infusion of mathematics into the middle school science classroom. The instrument can be used by teachers, administrators, teacher educators, and professional development providers. (See Appendix B for the instrument.)

Research Agenda

Although we believe that teachers prepared to teach both middle school mathematics and science may be better able to infuse mathematics into the science classroom, a research agenda is needed to provide evidence and support for this position as well as identify teacher competencies and student outcomes. To this end, research should be designed to explore the following questions, appropriate for both preservice and inservice middle school science teachers.

1. What are the mathematics teaching resources, strategies, and activities used by middle school science teachers?
2. What are the middle school science teacher competencies related to mathematics content knowledge and mathematics pedagogical content knowledge?
3. What are the middle school science teacher attitudes, perceptions, and dispositions related to mathematics?

4. What are student outcomes related to mathematics conceptual and procedural knowledge in a mathematics-infused science classroom?
5. What are student outcomes related to mathematics attitudes, perceptions, and dispositions in a mathematics-infused science classroom?
6. What is the support system (e.g., school organization, administrators, parents, community, assessment, financial resources) needed to facilitate the infusion of mathematics into the science classroom?
7. What are the changes in middle childhood science teacher perceptions related to the importance of and preparation for mathematics content knowledge and mathematics pedagogical content knowledge?

APPENDIX A

MATHEMATICS AREA OF CONCENTRATION AT THE OHIO STATE UNIVERSITY

(minimum 33 hrs)
Math 105 Mathematics Concepts for Teachers I 5 _____
Math 106 Mathematics Concepts for Teachers II 5 _____
Mathematics 109 Geometry and Measurement for Middle School Teachers 5 _____ ***(highly recommended)***
Select one:
Math 107 Mathematics Concepts for Teachers III 5_____ ***(highly recommended*)***
Math 116 Excursions in Mathematics 5_____
Math 255 Differential Equations 5 _____
Select one:
Mathematics 108 Number and Algebraic Structures for Middle School Teachers 5 _____ ***(highly recommended)***
Math 148 Algebra and Trigonometry 4_____
Math 150 Elementary Functions 5_____
Math 568 Introductory Linear Algebra 3-5 _____
Select one:
Math 111 Concepts of Calculus for Middle School Teachers 5 _____ ***(highly recommended)***
Math 117 Survey of Calculus 5_____
Math 151 Calculus & Analytical Geometry I 5 _____
Select one:
Stat 135 Elementary Statistics 5_____
Stat 145 Intro to the Practice of Statistics 5_____
Stats 427 & 428 Probability and Statistics for Engineering & Sciences 6 ____
Select one:
CS&E 101 Computer-Assisted Problem Solving 4_____
CS&E 201 Elementary Computer Programming 4_____
CS&E 221 Software Development Using Components 4 _____
GPA ________ TOTAL HOURS _______
****Math 107 is highly recommended for all Middle Childhood Math students admitted to the M.Ed. beginning Su07, and will be required for all students admitted Su09 and after.***

Appendix B

Mathematics Content Knowledge and Mathematics Pedagogical Content Knowledge Preparation for Science Teachers

Name ________________________________ Date ______________________

Check all that are appropriate and list the subject(s) taught.

________ Mathematics Teacher
Subject (s) ________________________
Subject (s) ________________________

________ Science Teacher
Subject (s) ________________________
Subject (s) ________________________

________ Mathematics Teacher Educator
________ Elementary School
________ Middle School
________ Secondary School

________ Science Teacher Educator
________ Elementary School
________ Middle School
________ Secondary School

________ Other
________________________________ (Please describe)

Check all that is appropriate to your position:

________ Grade 1 ________ Grade 2 ________ Grade 3

________ Grade 4 ________ Grade 5 ________ Grade 6

________ Grade 7 ________ Grade 8 ________ Grade 9

_________Higher Education
___________ Undergraduate
___________ Graduate

<u>With regard to Middle School Science Teachers,</u>

from the following list of Mathematics Content Knowledge and Mathematics Pedagogical Knowledge circle:

VI Very Important **GP Generally Prepared**

MI Moderately Important **LP Limited Preparation**

NI Not Important **NP Not Prepared**

MATHEMATICS CONTENT KNOWLEDGE PREPARATION

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

1.	VI	MI	NI	use a problem-solving approach to investigate and understand mathematical content	GP	LP	NP	1.
2.	VI	MI	NI	can communicate mathematical ideas in writing and orally, using everyday and mathematical language	GP	LP	NP	2.
3.	VI	MI	NI	can make and evaluate mathematical conjectures and arguments and validate their own mathematical thinking	GP	LP	NP	3.
4.	VI	MI	NI	can make connections among ideas in mathematics and connect mathematics to other disciplines and real-world situations	GP	LP	NP	4.
5.	VI	MI	NI	use mathematical modeling to formulate and solve problems from both mathematical and everyday situations	GP	LP	NP	5.
6.	VI	MI	NI	understand and apply concepts of number, number theory and number systems	GP	LP	NP	6.
7.	VI	MI	NI	understand and apply numerical computational and estimation techniques and extend them to algebraic expressions	GP	LP	NP	7.
8.	VI	MI	NI	understand and apply the process of measurement and measurement applications	GP	LP	NP	8.
9.	VI	MI	NI	use geometric concepts and relationships, including transformations, to describe and model mathematical ideas and real-world constructs	GP	LP	NP	9.

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

10.	VI	MI	NI	understand and apply the concepts of statistics and probability, including exploratory data analysis and experimental probability	GP	LP	NP	10.
11.	VI	MI	NI	use algebra to describe patterns, relations, and functions and to model and solve problems	GP	LP	NP	11.
12.	VI	MI	NI	understand the role of axiomatic systems in different branches of mathematics, such as algebra and geometry	GP	LP	NP	12.
13.	VI	MI	NI	explore the fundamental concepts of calculus through models, concrete examples, and use of calculators and computers	GP	LP	NP	13.
14.	VI	MI	NI	use algorithmic and recursive techniques in solving problems	GP	LP	NP	14.
15.	VI	MI	NI	use appropriate technology (including graphing calculators, spread sheets, and software packages) to explore and solve mathematical problems	GP	LP	NP	15.
16.	VI	MI	NI	have a knowledge of historical development in mathematics, including the contributions of underrepresented groups and diverse cultures	GP	LP	NP	16.

Mathematics Pedagogical Content Knowledge Preparation

Professional Knowledge

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

17.	VI	MI	NI	can identify and model strategies used for teaching the following strands for Middle Childhood: - problem solving	GP	LP	NP	17.
18.	VI	MI	NI	- numbers and number relations	GP	LP	NP	18.
19.	VI	MI	NI	- geometry	GP	LP	NP	19.
20.	VI	MI	NI	- algebra, patterns, relations, and functions	GP	LP	NP	20.
21.	VI	MI	NI	- measurement	GP	LP	NP	21.
22.	VI	MI	NI	- data analysis and probability	GP	LP	NP	22.
23.	VI	MI	NI	- estimation and computation	GP	LP	NP	23.
24.	VI	MI	NI	use calculators, computers, and other technologies as tools for teaching mathematics	GP	LP	NP	24.
25.	VI	MI	NI	use a variety of manipulative and visual materials for exploration and development of mathematical concepts for Middle Childhood	GP	LP	NP	25.
26.	VI	MI	NI	undergo the models for developing major concepts in grades K-3	GP	LP	NP	26.
27.	VI	MI	NI	develop mathematical concepts and procedures through interdisciplinary settings	GP	LP	NP	27.

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

Curriculum								
28.	VI	MI	NI	use a variety of resource materials such as software, print materials, and activity files in the learning of mathematics	GP	LP	NP	28.
29.	VI	MI	NI	select appropriate mathematical tasks that will stimulate students' development of mathematical concepts and skills	GP	LP	NP	29.
30.	VI	MI	NI	plan mathematical tasks and activities for students who are culturally diverse, those with limited English proficiency, and those with special needs	GP	LP	NP	30.
Instructional Management								
31.	VI	MI	NI	use oral and written discourse between teacher and students and among students to develop and extend students' mathematical understanding	GP	LP	NP	31.
32.	VI	MI	NI	create a learning environment in which students feel free to take risks	GP	LP	NP	32.
33.	VI	MI	NI	use various student groupings such as collaborative groups, cooperative learning, and peer teaching	GP	LP	NP	33.
34.	VI	MI	NI	accommodate different learning styles such as visual, auditory, and tactile	GP	LP	NP	34.
Professional Culture								
35.	VI	MI	NI	apply knowledge of current research and national, *Ohio*, and local guidelines relating to mathematics instruction	GP	LP	NP	35.
36.	VI	MI	NI	recognize the role of reflective practice, professional development, and active participation in the community of learners to their life-long growth as a teacher	GP	LP	NP	36.
Assessment								
37.	VI	MI	NI	use assessment in the classroom to monitor students' mathematical learning and to make instructional decisions	GP	LP	NP	37.
38.	VI	MI	NI	use a variety of methods to assess mathematical learning, such as open-ended questions, portfolios, and performance tasks	GP	LP	NP	38.

Perspectives on K-12 Engineering/Technology Education

Michael Hacker and David Burghardt

Despite its dependence on technology, U.S. society is largely ignorant of the nature, history, and processes of technology; and technology as a subject has received scant attention in the schools (NAE, 2000). In its authoritative report *Technically Speaking*, the National Research Council warns, "Although the United States is increasingly defined by and dependent on technology…its citizens are not equipped to make well-considered decisions or to think critically about technology (NAE, 2002)."

Technological literacy requires that children have a knowledge base not only about technology but also about the math and science that underlie it (NAE, 2000).

What is Technology?

Technology is a word that is used in various ways leading to a lack of clarity about its meaning. Sometimes the term denotes *technical means*; sometimes *products*; sometimes sets of *procedures*. Kline (1985) suggests that technology is viewed in four ways: as an artifact, as a methodology or technique, as a system of production, and as a socio-technological system. Technology is characterized by several attributes. These include:

1. The notion that technological solution-finding is an iterative process.
2. The idea that there is no "right answer." There are multiple solutions with different benefits and burdens. The search is for an *optimal* solution.
3. Trade-offs that are made between what is desired and what is feasible within real-world constraints of time, money, laws of nature, politics, etc. (This also may mean that certain groups profit while other groups are disadvantaged.)
4. The almost certain existence of unanticipated side effects that are sometimes negative and sometimes positive (Hacker, 1998).

The National Research Council maintains that high school students in general do not distinguish between the roles of science and technology. They particularly misunderstand the interrelationships: "Students as well as many adults and teachers of science indicate a belief that science influences technology…. Few students understand that technology influences science" (NRC, 1996).

According to Raizen et al (1995), "Generally both students and teachers believe that the subject matter in school is science and that technology means computers." The differences between the sciences and technology as disciplines must be clarified, not only for students, but for their teachers. Some of the obstacles to Technology Education implementation relate to public perception (party because technology is not well understood, partly because Technology Education is tainted by its traditions, and partly because Technology Education reform has not gone far enough).

Engineering and Technology Education

There is a growing movement within the Technology Education field to embrace an engineering education approach. NSF has funded The National Center for Engineering and Technology Education (NCETE). NCETE links technology educators with engineering educators in a symbiotic alliance to build capacity for research, nurture a cadre of talented, diverse leaders in engineering and technology education and infuses engineering design and analytical skills into K-12 schools (NCTET, 2004).

What is Engineering?

Why should students learn about engineering? How can it help them? To answer these questions we need to move beyond the workaday definitions that describe the professional practice of engineering, to the overall characteristics of engineering, the habits of mind and the engineer's way of viewing the world. Notice that the word engineer can be a noun or a verb. One can be an engineer, one can engineer a solution. The etymological root lies in the Latin word, *ingeniare*, to devise or design. The definition advanced by ABET is that "engineering is the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination." Webster's College Dictionary provides the following definition— "the practical application of science and mathematics, as in the design and construction of machines, vehicles, structures, roads and systems." These definitions belie the uniqueness of engineering, its body of thought, and the methodology, that it employs. Building on the ideas of C.P. Snow's *The Two Cultures*, engineers are optimists, they believe they can improve a design, create a solution, solve a problem; it is an outlook inherent to the profession, embedded in the engineering educational system.

Presently, through science education programs, schools do a fine job about teaching students about phenomena in the natural world and why things happen as they do. There is a paucity of attention paid to teaching students about how the systems, artifacts, and environments that comprise the human-made world come into being.

Engineering and Technology Education

To stimulate a conversation about how a school-based approach can provide students with an understanding of the human-made world, *engineering and technology education* (ETE) will be discussed as a single program area designed to instill understanding about how the built environment is designed and engineered.

To help us gain greater perspective, the information in Table 1 seeks to contrast the differences between mathematics, science, engineering/technology and social science/humanities. These are only thumbnail sketches, but they can highlight the differences between disciplines and help in thinking about the overarching themes that define engineering, noun and verb.

Science is the study of the natural world, a discipline engaged in discovering the whys and wherefores of natural phenomena. There is a process for this investigation, scientific inquiry, in which a hypothesis is posed and logical investigations are undertaken to confirm or deny the hypothesis.

Mathematics has its own philosophy and patterns. It is often used by engineers and scientists to model designs or represent natural phenomena, such as Newton's second law of motion, $F = m a$. There are rules of mathematical analysis (theorems) that allow us to manipulate such equations. A publication by the NRC, *Helping Children Learn Mathematics*, discusses the big ideas and habits of mind needed to be mathematically successful.

The social sciences and humanities provide an entirely different view of the world, a world shaped by human perceptions and understandings. For instance, a novel or a political or social event can by analyzed from many different perspectives. There is no correct answer, but justified opinions.

Engineering/Technology	Science	Mathematics	Social Science/Humanities
Study of the human-made world	Study of the natural world	Study of mathematical constructs	Study of human mind and perception
Engineering design	Scientific inquiry	Mathematical analysis	Rhetoric and criticism
Iterative design process, optimum solution	Hypothesis testing and evaluation	Theorems, proofs, rational constructs	Eclectic methods, comparative values
Artifact produced	Theory confirmed	Theorem validated	Opinion rationalized

Table 1. Comparison among different fields of thought.

Engineering and technology uniquely connect these disciplines. In creating the human-made world, engineers and technologies must use and apply knowledge from science, mathematics and social sciences and humanities. In contrast to scientific inquiry and mathematical analysis, engineering and technological design does not seek a unique or correct solution, but rather seeks the best or optimal solution after a variety of factors are weighed, such as cost, materials, aesthetics, and marketability. The design process is iterative, creative, and nonlinear. The solutions are tempered by our societal values. Hence, the optimal solution for one person may not be the optimum solution for another. Because we can bring our values to our design solutions, engineering design can be a very engaging pedagogical strategy.

Engineering and technology are ways of understanding the human-made world, how it was created, how it functions and how it might be changed. Engineers and technologists realize that what has been made can be improved. Even if it were optimal at a moment in time for the specifications and constraints that were imposed, new technologies, new opinions, new perspectives allow for different solutions. This is a very empowering feature of engineering and technology and is in significant contrast to scientific and mathematical understandings, where hypotheses and theorems may be refined, but in the main they remain unalterable. In our discussion of K12 ETE, we are using the following definitions:

Engineering — creating the human-made world, the artifacts and processes that never existed before. This is in contrast to science, the study of the natural world. Most often engineers do not literally construct the artifacts, they provide plans and directions for how the artifacts are to be constructed. Artifacts may be as small like a hand calculator or large like a bridge. They also design processes, the processes may be those used in chemical and pharmaceutical industries to create chemicals and drugs, to directing how components are put together on an assembly line, or indicating how checks are to be processed in banking.

Engineering and Technology Education — An integrating discipline designed to develop technological literacy as part of all students' fundamental education through an activity-based study of past, present, and future technological systems; their resources, processes, and impacts on society (NYSED, 1989).

Engineering Design and the Engineering Design Process — the iterative process for creation and manipulation of the human-made world. The process combines knowledge and skills from a variety of fields with the application of values and understanding of societal needs to create systems, components, or processes to meet human needs. Initialized by problem definition, followed by clarity of the specifications that the designed product must meet, the open-ended engineering design process optimizes competing needs and constraints, and uses modeling and analysis to drive the creation of new engineered solutions to serve humankind.

Engineering design is not trial-and-error gadgeteering. Engineers use their knowledge of science and engineering science to understand what is happening physically, their use of mathematics to create models that may be analyzed, and their understanding of prior technological solutions so they can innovate. Then they create design solutions. This is in contrast to the process used by inventors who may gadgeteer, arriving at a workable solution that they can patent or manufacture. The use of modeling, with its inherent predictive analysis, is one of the significant differences between engineering and technology education, and engineering and art.

Engineering design and the design process are inherent to engineering, as the roots of the word engineer are linked to the design process. But what of concepts like optimism and creativity? We need a framework that provides us with a way to visualize/describe the various attributes of engineering habits of mind (visualization, creativity, connecting science, mathematics, social sciences and humanities, optimism, how things work, systems thinking) and engineering practice (engineering design including optimization, specifications and constraints, societal impacts, modeling).

Modeling — a way to better understand what an actual artifact or process is experiencing. Consider a wooden plank used as a foot bridge across a stream. An engineer might be asked to predict whether or not the plank would break if subjected to a certain load. The engineer creates a **representational model** of the plank, including its size, assumptions about physical properties such as Young's modulus and yield stress, about property variation, and about how the plank is secured on the banks of the stream. Using the representational model, the engineer creates a free-body diagram and from the free-body diagram develops a **mathematical model** based on laws of mechanics. The accuracies of the representational model and the mathematical model determine how valid the predictions are. In the design process, engineers create representational models of solutions and then mathematically characterize (model) them (e.g. free-body diagrams) to predict behavior.

Optimization — the process of improving each alternative design, or improving each part of a design. Often, different alternatives will be better in different ways. For example, one material may be stronger, but a second material may cost less. When choosing the best solution, normally requires trade-offs. That is, one must give up one desirable thing for another. In such cases,

Modeling in K-12 ETE

In K-12 ETE, modeling is the combination of representational models, which may be drawings or three-dimensional renditions, and mathematical models based on or incorporated with the representational models. In early grades the physical model will have certain attributes that are mathematically determined. A fourth grade student could design a scaled version of a classroom. They would create scale drawings which would later be transferred to three-dimensional renditions of the design. The renditions could be made of cardboard and there is a balance between the physical representational model and the mathematical model.

As the students gain greater knowledge and skill, the mathematical modeling aspect can increase in sophistication. In 11th and 12th grades, students could represent actual electric and electronic circuits with circuit elements-resistance, capacitance, inductance, voltage and current sources-and then use mathematical models of the circuit elements to predict behavior.

To mirror how contemporary designing is done and to meet our *Internet native* students where they are, establishment of a “hybrid” modeling approach is proposed. Hybrid modeling integrates screen-based 3-D simulation and real-world physical modeling. Once designs are optimized on-screen, ETE students construct physical models and compare their functionality and effectiveness to the simulated virtual models.

deciding which criteria are the most important helps in determining the best solution to the problem. The idea is to decide upon a design that best meets the specifications, fits within the constraints, and has the least number of negative characteristics.

Specifications and Constraints — **Specifications** are performance requirements, or output requirements, the design solution must fulfill. The design specifications for toothpaste might include that it cleans plaque form teeth, tastes good and can be squeezed easily out of a tube. A design specification for a certain type of car might be that it can accelerate from 0-60 mph in under ten seconds. Design specifications often include safety considerations. Stating that a passenger elevator must have a safety factor ten times greater than the load it is expected to carry, or that the front of a car will not be damaged after a crash of 5 mph are specifications the design must meet. **Constraints** are limitations imposed upon the design solution. Constraints are often related to resources such as the materials the designer is able to use, how much money a finished product can cost, or how much time can be devoted to producing it. Other limitations can relate to the availability of certain kinds of workers or by the need to limit negative effects of the design on the environment.

Technology — encompasses both the tangible artifacts of the human-designed world (e.g., bridges, automobiles, computers, satellites, medical imaging devices, drugs, genetically engineered plants) and the systems of which these artifacts are a part (e.g., transportation, communications, health care, food production), as well as the people, infrastructure, and processes required to design, manufacture, operate, and repair the artifacts. [NAE, 2002b]

The *Standards for Technological Literacy* (2000) and *Project 2061* (1993) discuss the designed world and learning outcomes for K-12 associated with the ETE perspective. Certainly design plays an important role, as do ethics and the impact of technology on society. In addition, technical content, such as transportation systems and manufacturing systems, are viewed as important to know. The idea of systems thinking is supported and connections are made to natural and mathematical systems.

ETE Broad Themes and Strands of Knowledge

The National Research Council uses the concept of strands of knowledge as a way to visualize the content areas in mathematics and science. The following is a list of various thematic aspects (strands) of engineering and technology that could be included in K-12 ETE.

ETE Habits of Mind
Visualization
Creativity
Connections to S, M, SS/Humanities
Optimism
Technology (how things work)
Systems thinking (subsystems, feedback)

Engineering and Technological Design
Design informed by knowledge and skill
Optimization, trade-offs
Modeling, predictive analysis
Ethics, societal impacts

Potential connections between ETE habits of mind and engineering and technological design as illustrated in Figure 1, on the following page.

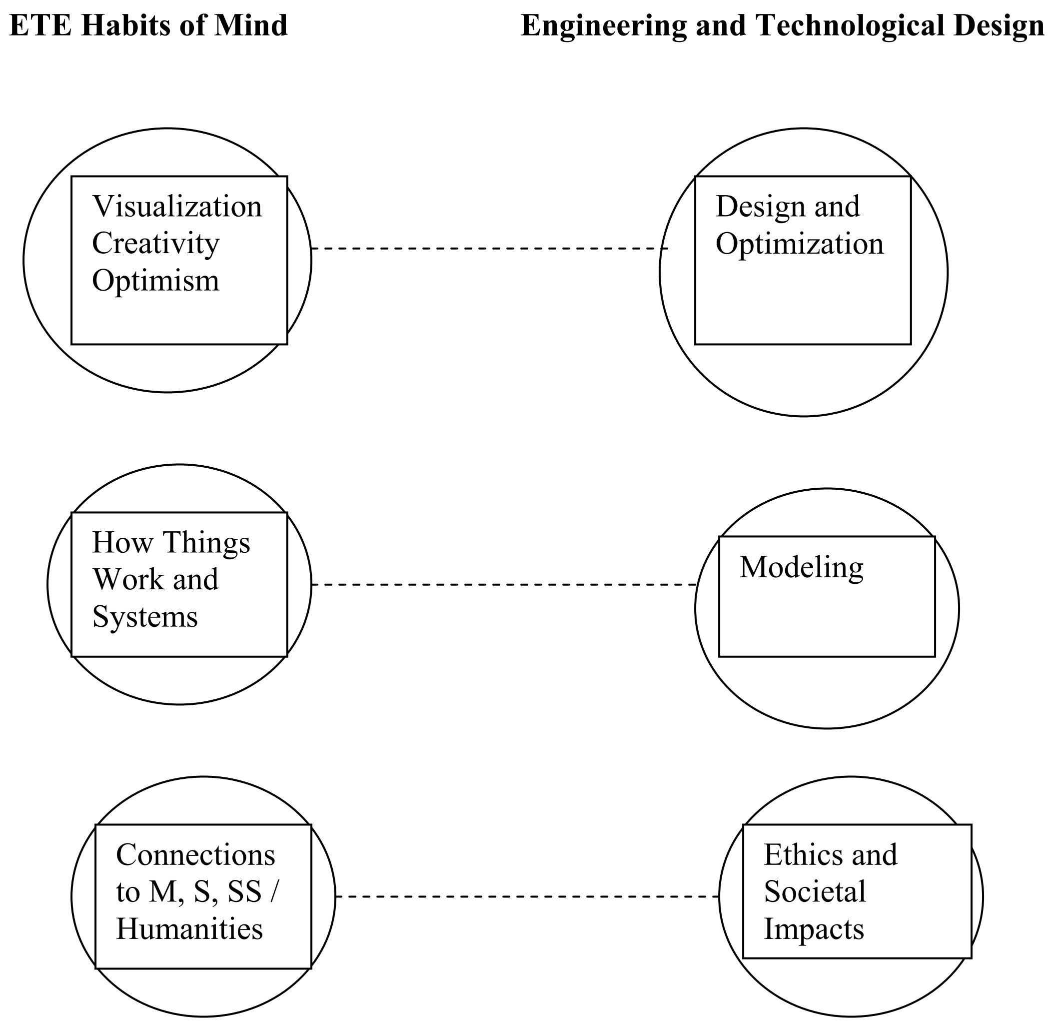

Figure 1. Connecting Strands of K-12 ETE Content Knowledge

K-12 Engineering and Technology Education for All Students

In thinking about K-12 ETE for all students, we need to consider children's developmental capability, what the classroom environment typically is, and what the expectations are in terms of educational objectives. The K-12 spectrum is often divided into grades K-5, 6-8, and 9-12. Table 2 indicates what how ETE might appear at different grade levels.

Grades K-5	Grades 6-8	Grades 9-12
In these grades students are primarily in self-contained classrooms with their teacher. The general focus of education is on literacy and math reasoning. There often are specialists for science, art and physical education. It is recommended there be an ETE grades K-5 specialist as well to support the classroom teacher. In this role, the specialist will help develop curriculum that explains the human-made world, how things work, systems thinking, societal impacts of technology. Design projects can support other curricular areas, such as creating robots from cardboard boxes and paper rolls in kindergarten that support measuring, to creating models of buildings in fifth grade that must meet certain volume and surface area requirements. Curricula like *Engineering is Elementary* can supplement or replace science activities, though the thrust of NAE K-12 effort is not selling ETE, but using the pedagogical strengths that ETE brings to develop student knowledge in core academic disciplinary areas.	At these grades students often move as a class cohort, changing teachers for different content areas. The general focus remains on literacy and math, but broadens to include social studies and science. It is recommended there be a secondary education ETE specialist who will have two roles, one analogous to that of the K-5 ETE specialist and the other role in providing a year-long ETE course for all students. This course could be similar to middle school ETE courses that currently exist, with strong connections to grade-level-appropriate math and science. Much of the content of these courses are design-based projects. The projects begin to use some modeling for predictive analysis. Support to academic areas can include information about societal impacts, as well as mini-design projects. There could be some design-based science labs, replacing existing science experiment labs.	At these grades students move as cohorts and as individuals, as they begin to tailor their educational programs. There is expanding accountability in science and social science and continuing accountability in language arts and mathematics. It is recommended there be a secondary ETE specialist who will have two roles: 1) to support ETE across the curriculum, and 2) to provide a year-long course for all students in Principles of Engineering. This course would focus on case studies feature societal impacts and ethics. For instance, there could be an emergency shelters case study that addresses environmental impacts, and ergonomic design. Gathering and using data in the case studies will be important, as well as modeling the solution prior to prototype design. Support to academic areas can include information about heat transfer, area and volume of geometric shapes, surface area/volume ratios, and societal impact. Some design-based science labs might replace existing science experiment labs.

Table 2. ETE at different grade levels

Contrasting K-12 ETE with K-12 Science.

According to *Taking Science to School* (NRC, 2007), the following themes are necessary for students to be proficient in science. Students should

1) know, use and interpret scientific explanations of the natural world;
2) generate and evaluate scientific evidence and explanations;
3) understand the nature and development of scientific knowledge; and

4) participate productively in scientific practices and discourse.

How is science currently taught? What are the attributes at the different grade levels? In general, there is more focus on living things than there is on inanimate matter. Children begin to learn about themselves and their interactions with the natural world around them. As this progresses to middle school, the physical world becomes more important, but less so than the living world. Science is primarily qualitative at the elementary and middle-school levels. In high school, specialty content areas in biology, chemistry, physics, and earth science are often included in student requirements. There is an increase in quantitative reasoning in chemistry and physics; earth science and biology often are relatively more qualitative. All require laboratory experiments and reports, which can include data analysis and explanations, particularly so at the high school level.

The information in Table 3 is based on the New York State Core Science Standards which match national science standards.

Grades K-4	**Grades 5-8**	**Grades 9-12**
Science is often taught by the classroom teacher, perhaps two periods per week. In general, elementary school teachers have had little science (or math) at the college level. Some more affluent schools have science specialists who meet with the class; there may be science specialists to assist classroom teachers. There may be science kits (e.g. Foss) provided and teachers follow the provided guide. The goal is to understand major themes in the natural world such as earth and celestial surroundings, weather and climate, properties of matter, energy forms, living and non-living things, genetics, evolution, reproduction.	Science is taught by a science specialist, ideally certified in a content area of secondary science, though grade 6 still is elementary in terms of certification. Students may meet daily for science, since it is required each year, for the whole year. The topics are similar to those at the elementary level, except the detail is greater. Major topics include human systems, cells, genetics, reproduction, evolution, earth and celestial surroundings, erosion, rocks and minerals, earthquakes, properties of matter, chemical and physical changes, energy forms.	Science is taught by a science specialist. Students take a science course for the whole year. Courses typically are chemistry, physics, earth science (environmental science), and biology. Students meet for lecture and laboratory classes.

Table 3. Science at different grade levels

In analyzing Tables 2 and 3 (K-12 ETE and K-12 Science), very little overlap is seen in terms of key ideas. Science is concerned with understanding the natural world, ETE is concerned with understanding the human-made world.

Comparing the strands of K-12 ETE (noted in Figure 1) with the four themes from *Taking Science to School*, there is again little in the way of connection. For instance, "understanding nature and the development of scientific knowledge" does not directly link to any of the ETE strands (it indirectly links to "making connections to M, S and SS/Humanities). This is not to say that connections cannot be made, the content of *Engineering is Elementary* does just that in replacing some science curriculum with engineering and technology curriculum. However, the strength of K-12 ETE is including material related to all the strands in Figure 1, not just one or two.

Importantly, another aspect of K-12 ETE that needs to be explored is using design as a pedagogical approach. This has had success in different content areas; success being defined as improved student learning and interest in the core content (Koch and Burghardt, 2002) (Akins and Burghardt, 2006).

Contrasting K-12 Engineering with College Level Engineering

There are significant differences between K-12 ETE and College Level Engineering, differences in emphasis for the different conceptual areas. The six strands noted in Figure 1 are more equally weighted with one another in K-12 education, with the exception of the first strand dealing with creativity, which may be smaller than the rest in terms of instruction, though not necessarily in importance. When we think about teaching about human-made world for all K-12 students, it is one strand is not more significant than another.

However, in college the modeling strand begins to widen and the other strands become support areas. Much of the engineering curriculum is primarily devoted to analysis (modeling) and secondarily to systems and design. The other strands are of lesser curricular importance. The ABET accreditation guidelines, which drive curriculum, enforce this view. Similarly, the Professional Engineering Fundamentals examination focuses primarily on engineering analysis, so majors that find the PE license important need to assure students an education congruent with it.

Conclusions

Returning to the initial questions, engineering (the verb) provides all students with problem- solving strategies for understanding the human-made world and for applying concepts in mathematics, science and social science and humanities. Engineering (the noun) can refine these skills for students interested in further exploring the human-made world. The prime goal for K-12 ETT relates to furthering the intellectual capability of all students to understand the technologically complex world we live in and through a system (engineering) that meaningfully connects mathematics, science and social sciences and humanities. In terms of K-12 education, the habits of mind and engineering design would be part of all students' education, K-12. Thus, ETE is the study of the human-made world.

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Engineering Curriculum as a Catalyst for Change

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This paper focuses on the elementary level, describing some changes that an engineering curriculum, *Engineering is Elementary*, has promoted among teachers and students. It provides some evidence that an integrated, cross-curricular approach to engineering can be a powerful tool in fostering pedagogical change among teachers and enhance students understandings of scientific concepts.

The *Engineering is Elementary (EiE, www.mos.org/eie)* project aims to foster engineering and technological literacy among children and their educators. EiE is creating a research-driven, standards-based, and classroom-tested curriculum that integrates engineering and technology concepts and skills with elementary science topics. EiE materials also connect with literacy, social studies, and mathematics. Through engaging engineering design challenges children are
invited to apply their knowledge of science, engineering, and their problem solving skills, as they design, create, and improve possible solutions.

The *Engineering is Elementary (EiE)* project began five years ago as a response to a challenge to figure out how to include engineering and technology in a number of elementary schools in Massachusetts. The state science Frameworks and assessments had recently been expanded to include technology/engineering. However, with the new learning objectives efforts seemed stalled; few districts were actually addressing the new standards due perhaps to a lack of curricular materials and teacher professional development programs that supported the new engineering/technology Frameworks.

The inclusion of a new discipline represented a potential opportunity: elementary educators' lack of exposure, experience, and education about engineering meant that teachers would not bring ingrained models for instruction or habits of teaching that needed to be undone. Because engineering has almost never been taught at the elementary level, we had the chance to model what we thought engineering instruction should look like from the field's inception. We could offer original perspectives rooted in our philosophy of how children should learn (and teachers might teach). Thus, instead of undoing existing habits and working with many competing instructional philosophies and paradigms, we had the chance to provide a strong, consistent model for engineering almost from scratch.

Theoretically, this could be a great opportunity. In reality, the work required introducing a new, intimidating discipline and changing school curricula, classrooms, and teachers—a daunting task that left team leaders skeptical about the prospects for wide-scale or long-term success. However, early qualitative and quantitative results demonstrate that the Engineering is Elementary project has catalyzed changes in schools' acceptance of a "new" subject, in teachers' pedagogical styles and comfort teaching engineering, and in children's understanding of science and engineering concepts and attitudes toward science and engineering fields and careers. This paper will focus on two changes: changes elementary teachers report in their pedagogy as a result of engaging in engineering professional development workshops and curriculum implementation and changes in student interest in and learning about science and engineering. Of particular interest are early results that suggest that EiE can help close the achievement gap between students from low and high socioeconomic backgrounds.

Some Background about the Curriculum

The design of the EiE curriculum is rooted in Wiggins and McTighe's [1] "backward design" process in which assessment is closely linked with curricular development. Interplay between a set of commitments held by the EiE developers, copious feedback from classroom teachers, and results from quantitative and qualitative assessments collected from students shaped the final curriculum design. A number of core curricular commitments held by the development team served as a set of constraints and criteria for the program. These included that the curriculum:

- must be inviting, accessible, and interesting to *all* students, particularly populations that are currently underrepresented in STEM or "at risk"
- focus on engineering as a problem-solving process and way of thinking (instead of communicating a set of facts)
- be able to be *realistically* used by teachers and schools (e.g., low-cost materials and minimal professional development)
- promote pedagogical strategies consistent with socioconstructivist learning

Interested in STEM education as a tool for social justice, the project team was especially attentive to creating a program that would engage underrepresented and "at risk" students (girls, students of color, students from low socioeconomic backgrounds, English language learners, students with physical and cognitive disabilities). Thus, previous experience and scholarly literature suggested that the project also needed to:

- Create engineering design challenges that demonstrate the role engineers play in helping people, animals, or society
- Set the projects in a larger context to help students understand where and how the engineering information and tasks might be relevant
- Provide engineering role models from both sexes, from a variety of races, ethnicities, and abilities/disabilities who have a wide range of hobbies and interests
- Ensure that design challenges are truly open-ended with no single correct answer
- Cast failure as a necessary and inherent part of engineering that invites subsequent improved designs
- Make explicit the steps of the process to scaffold student work (without making the process formulaic)
- Assume no previous familiarity with either the materials or terminology used
- Develop challenges that use very low-cost with readily available materials
- Cultivate a culture of collaboration and teamwork (not one of competitive individuals)
- Foster opportunities for all students' ideas to be heard and considered
- Require students do active, hands-on engineering (not read about it)
- Produce materials that could easily be scaled up or down to meet the needs of a variety

of types of learners
- Focus on developing problem-solving processes

From our first meeting, the science coordinators and elementary teachers partners who have helped to frame and test our materials, insisted that any effort to include engineering at the elementary level *must* integrate with subject matter they were already teaching. They clearly articulated their concern that they could not teach more content without it closely connecting to topics that they were already expected to cover. Guided by this mandate, the EiE team chose elementary science as the subject that would most closely integrate with and structure the EiE units. Twenty commonly taught elementary school science topics were identified; EiE engineering units would build upon and reinforce through application these science concepts. The subsequent persistent, unremitting call from teachers to connect EiE with mathematics as well has launched a newer effort with this discipline.

To set a context for the unit, to introduce engineering to teachers through a comfortable medium (language arts), and to piggyback on the abundant literacy minutes available in elementary school classes, EiE units begin with an illustrated storybook. In the stories, which are set in cultures and countries around the world, a child protagonist confronts a real-world problem. An adult engineer in the child's life introduces the engineering design process and invites the child to apply it to develop a solution. In their classroom, students are then challenged to solve a similar problem.

As requested by teacher partners, the 20 EiE units all have a common four-lesson structure. In the first lesson a context is set and the challenge introduced through an engineering story. Lesson 2 has students explore the kinds of work that engineers in the unit's field of focus (e.g., electrical engineering) might do. Lesson 3 guides students as they investigate through experimentation the materials and their properties that they will use in Lesson 4 where they engage in a five-step engineering design process to design, create, and improve a technology. The EiE unit guide contains teacher lesson plans, student duplication masters (worksheets), background resources for the teachers, and assessment items.

All EiE materials go through local pilot testing and national field testing in five states (MA, CA, CO, FL, MN). Feedback from teachers as well as quantitative student assessments are collected and analyzed and results are used to modify the curriculum.

Changing Teachers' Knowledge, Comfort, and Practice

Perhaps the biggest hurdle to elementary teachers' classroom implementation of engineering is their perception of engineering as a discipline that is too difficult for them and their students. A central goal of professional development is to defuse elementary teachers' feelings of ineptitude through engagement. Helping teachers to understand that they already know and use engineering concepts and having them do EiE engineering challenges supports teacher implementation by making them feel comfortable and confident so that they can introduce engineering to their students. To help support teachers' infusion of engineering topics into their classrooms, EiE staff have offered close to 200 professional development programs to thousands of teachers and have also trained approximately 100 teacher educators who in turn offer EiE professional development in diverse localities across the country. Professional development may range from a program that is two hours to one that is more than two weeks in length.

As we have worked with teachers, they have consistently described some effects of the EiE program. Some of these have to do with changes in their knowledge and the way they taught. Others focused on their students' learning and engagement. Teachers offered that the professional development and the EiE curriculum had them thinking about engineering and the human-made world in which they lived in a new way. They felt more knowledgeable about engineering and routinely recognized it in the world around them.

Perhaps more interesting, however, was that quite a few teachers also reported that they felt they had fundamentally changed the way that they teach as a result of professional development with EiE. Although many teachers professed to doing open-ended or inquiry-based science teaching before attending an EiE professional development workshop, they subsequently related that, in fact, the EiE design challenges were the first time that they had encountered a truly open-ended problem with no single correct or expected answer and no set answer key. According to these teachers, the experience sparked them to become more comfortable with open-ended problems and reconsider and alter the way that they posed questions in science and other subjects as well as the way they led their students through problem-solving.

These teacher-reported changes were intriguing. Although the EiE development team hoped to affect teachers' understandings of the prevalence of engineering and their comfort using the curriculum, scaffolding changes in pedagogical style in fields other than engineering was not something the team had aspired to or even considered. However, the prevalence of teachers' accounts led us to try to capture some of these data in a more systematic way. The EiE team worked with two different evaluators, Campbell-Kibler Associates Inc. and Davis Square Research Associates, to craft teacher surveys that would begin to investigate pedagogical changes that were happening in classrooms. Both of the studies suggest that EiE professional development and/or implementation is affecting teachers' instruction—not only do teachers report being more knowledgeable and comfortable with engineering and using engineering in their lessons but they also report changes in their pedagogical methods.

The Campbell-Kibler study [2] collected pre and post assessments from 24 field site teachers in four states (CA, CO, MN, FL) who had attended a 3-6 hour EiE workshop and then implemented an EiE unit. The Davis Square Research Associates (DSRA) study [3] collected retrospective
data from 120 teachers from Massachusetts who had participated in a five day EiE professional development program and then implemented a unit. The data are all self-reported and the majority of the sample had implemented only one EiE unit in their classroom (8-10 hours of classroom instruction).

<u>Changes in Teachers' Knowledge and Confidence</u>

As a result of the week-long professional development and subsequent EiE unit implementation, teachers reported a change in their understanding of what engineering is and their confidence in teaching engineering to their students. Teachers reported that they are confident, enthusiastic, and committed to teaching engineering concepts to their children.

Table 1: Teachers' Understanding and Confidence Teaching Engineering
(Scale: 1=Not at all; 6=A great deal; N≈120).

Item	Before EiE	Since EiE	Effect Size
I understand the range of engineering disciplines.	2.41	5.16*	0.83
I understand what engineers do.	2.96	5.31*	0.79
I understand the engineering design process.	2.33	5.41*	0.81
I incorporate engineering concepts into my teaching.	2.08	4.43*	0.72
I am confident teaching engineering and technology concepts.	2.28	4.60*	0.74
I am confident teaching science concepts.	4.27	5.08*	0.39
I am enthusiastic about teaching engineering concepts.	2.71	5.31*	0.72
I am committed to engineering teaching and learning.	2.50	5.03*	0.72
I am confident guiding my students in an engineering design challenge.	2.38	5.01*	0.78

*Significant at *p*<.001 (paired samples t-test)

When asked to rate the degree to which they used engineering in their classrooms, teachers' reported their use of engineering increased between a pre and post assessment in all eight areas. Particularly large increases were found in the frequency with which teachers described engineering careers to their students, used engineering examples in science lessons, and, most impressively, used an engineering design process in their science classes. They were also significantly more apt to use an engineering design process in other areas as well, including both math lessons and areas outside of math and science. Teachers quickly connected engineering to other subjects—it is not confined to a stand-alone subject, but rather integrated, especially with science and mathematics.

Table 2: Teachers' Use of Engineering in Their Classrooms
(Scale: 1 = Almost Always, 2 = Pretty often, 3 = Once in a while, 4 = Never; N≈24)

	Pre		Follow-up		Statistics	
	Mean	**SD**	**Mean**	**SD**	**t-test /probability**	**Effect size#**
I use engineering examples in science lessons	3.17	.83	2.35	.78	4.23/.000	1.02
I use an engineering design process in science lessons	3.17	.94	2.26	.81	4.61/.000	.95

I describe engineering careers to my students	3.33	.82	2.54	.98	3.8/.000	.87
I use engineering examples in math lessons	3.5	.61	2.85	.88	3.32/.002	.86
I talk about the courses and skills needed to go into engineering	3.46	.833	2.75	1.07	3.33/.001	.74
I use engineering examples in subject areas other than math and science	3.4	.75	2.95	1.0	2.27/.018	.53
I use an engineering design process in subject areas other than math and science	3.45	.83	2.95	1.05	1.88/.036	.53
I use an engineering design process in math lessons	3.55	.70	3.15	.99	1.9/.036	.47

Teachers also reported changes in their pedagogical strategies. After participating in EiE, teachers significantly increased their use of problem-solving strategies not explicitly related to engineering in their teaching. After using EiE, teachers evinced improved attitudes toward problem-solving strategies and used more inductive methods. Not only did teachers increase their use of engineering in their classrooms, but they significantly increased their use of other problem-solving strategies and increased the already frequent degree to which they asked students what they know about the topic being covered.

Table 3: Changes in Teacher Instructional Pedagogy

(Scale: 1 = Almost Always, 2 = Pretty often, 3 = Once in a while, 4 = Never; N≈24)

	Pre		**Follow-up**		**Statistics**	
	Mean	SD	Mean	SD	t-test /probability	Effect size
I ask students what they know related to the topic being covered	1.62	.71	1.17	.38	2.88/.008	.8
Students use things from everyday life in solving problems	2.39	.66	2.0	.74	2.4/.025	.56
Students work on problems for which there is no immediately obvious method of solution	2.92	.58	2.54	.83	1.99/.06	.53
Students explain how they solve complex problems	2.7	.62	2.33	.76	3.19/.004	.53
Students explain orally or in writing the rationale behind the problem solving strategies of other students	3.04	1.0	2.62	.92	2.01/.06	.4
Students work together in pairs or small groups	1.58	.58	1.46	.51	NS	
Students collect data or information to analyze	2.21	.78	2.08	.65	NS	
Students work on projects	2.17	.70	1.96	.75	NS	
Students explain orally or in writing their problem solving strategies	2.17	.70	2.12	.74	NS	
Students solve the same problem using more than one method	2.35	.78	2.13	.17	NS	
I use practical or story problems related to everyday life	2.04	.69	1.79	.88	NS	

Table 4: Participant Self-Reported Change
(Scale: 1=Not at all; 6=A great deal; N≈120)

Item	Before EiE	Since EiE	Effect Size
I am confident teaching problems that don't have one right answer.	4.16	5.22*	0.44
I am confident facilitating a classroom driven by student inquiry.	4.26	5.11*	0.42
I lead hands-on activities that promote learning by doing.	4.54	5.22*	0.36
I encourage my students to learn from their mistakes.	5.23	5.55*	0.11
Students work collaboratively.	4.16	4.68*	0.32
Students manipulate data.	3.49	4.16*	0.40
Students undertake open-ended projects.	3.50	4.22*	0.31
Students collaboratively discuss how to solve problems.	3.68	4.51*	0.40
Students explain their problem-solving strategies.	3.88	4.54*	0.33
Students explore problems related to everyday life.	3.29	4.28*	0.47
Students learn about engineering examples.	2.08	4.41*	0.67
Students use an engineering design process.	1.90	4.30*	0.64

*Significant at $p<.001$ (paired samples t-test)

EiE training and implementation had a strong positive impact on these teachers' instructional behavior. Not only did teachers include more engineering examples, concepts, and career information in their classes, they also incorporated more problem-solving strategies in their science instruction, their math instruction, and other areas.

In terms of the effects of participation in EiE on the respondents' teaching in other areas, the teachers answered with a significant (meaning, with a greater-than-expected consensus) that participation had a moderate effect on their teaching of other content.

Table 5: Additional Effects on Other Subject Matter Areas
(Scale:1=No Effect; 6=Great Effect; N≈120)

Please indicate the extent to which your participation in EiE has had an effect on your teaching in these subjects:	**M**
Math	3.57*
Literacy/Language Arts	3.34*
Social Studies	3.15*

*Significant at $p<.05$ (Kolmogorov-Smirnov statistic)

When asked to elaborate on what the changes were, teachers mentioned an increased use of inquiry, or uses of the engineering design process applied to areas not normally characterized as unique to engineering. The agent for these changes was alternately the teacher and the students. For example, elementary teachers responded:

- *I do more open ended inquiry-based lessons. Exploring concepts rather than one answer.*
- *I would ask more open-ended questions of the students as well as ask them how else they might find a solution.*
- *Students gained skill in their ability to articulate the process they used in designing their solutions to problems*
- *When there is a new concept in math the students look at the way they can incorporate the design process into finding the solution. They now realize better that there may be several paths that they could follow in order to reach the solution.*
- *When there is a new concept in math the students look at the way they can incorporate the design process into finding the solution. They now realize better that there may be several paths that they could follow in order to reach the solution.*

Teacher Reports of Student Benefit

Teachers also spoke passionately about the effects the EiE materials were having on their students. They "knew" that students were learning the science better when they studied it with engineering than when they only had the science. They recounted stories of students' piqued interest and follow-up actions with respect to engineering careers. Students were begging to do EiE engineering units, educators dangled EiE as a "prize" for good behavior during other more rote lessons of the day, and teaches told stories of children staying in during recess or continuing engineering challenges at home. Teachers professed that the materials were particularly powerful because they engaged the children who were often disenfranchised, acted out during class, or struggled with language and academics.

As the stories and anecdotes began to accumulate, the EiE team turned its attention to gathering more quantitative data to probe whether such effects might be captured. We began by first surveying EiE teachers, asking them about their perceptions of student learning and engagement. When asked to compare EiE with traditional science content, the responses of the participants were overwhelmingly positive and nearly unanimous—teachers felt that with the engineering curriculum students learned the science concepts better; were more engaged, collaborative, and creative; and made more real world connections.

Table 6: Student Benefits Relative to Traditional Content

(Scale: 1=Strongly disagree; 6=Strongly agree; N≈120)

Based on your experience teaching EiE (in comparison to teaching traditional elementary science curricula) please rate the degree to which you agree with the following statements:	**M**
Students learn science concepts better	4.69*
Students are more engaged	5.14*
Students are more collaborative	4.73*
Students are more creative	4.85*

Based on your experience teaching EiE (in comparison to teaching traditional elementary science curricula) please rate the degree to which you agree with the following statements:	**M**
Students make more real world science/engineering connections	5.29*

*Significant at *p*<.001 (Kolmogorov-Smirnov statistic)

Interested in teachers' perceptions that the engineering activities worked with all types of students, we also asked them how well the curriculum worked with a variety of different groups of students. Overall, the teachers reported that the curriculum worked for their students. Further investigation yielded no significant differences among the various student groupings, a clear indication that the teachers found that EiE worked well with diverse populations, whether low- or high-achieving.

Table 5: Teacher Reports of Student Benefits

(Scale: 1=Strongly disagree; 6=Strongly agree; N≈120)

Please indicate how strongly you agree. EiE works well for my students	**M**
with cognitive challenges	4.78*
with linguistic challenges	4.50*
with behavioral challenges	4.48*
who are gifted and talented	5.39*
who are girls	5.08*
who are children of color	5.40*
who are at-risk in other ways	4.78*

*Significant at *p*<.001 (Kolmogorov-Smirnov statistic)

When asked to expand upon their ratings, teachers indicated that students benefitted in a variety of ways: cognitive, behavioral, and social. The materials were judged engaging and students were able to benefit from their uses. For example, teachers responded:

- *Children who are not always the most successful academically have a real opportunity to shine here. Also, teamwork is emphasized and valued.*
- *Your program works for most students because of the hands on component. They are involved so there less time for them to be off task. it is a great time to allow the brighter students to lead and for the more challenging student to fully participate.*
- *Kids who are behaviorally challenged are highly engaged, and so usually stay on task w/ hands-on work.*
- *The unit …was a huge success across the board. It provided the brighter students to do individual investigations and have extensions to the activities. My behavior students were entirely connected to what was going on*
- *This program works well for students with linguistic challenges b/c it is so hands-on and visual.*

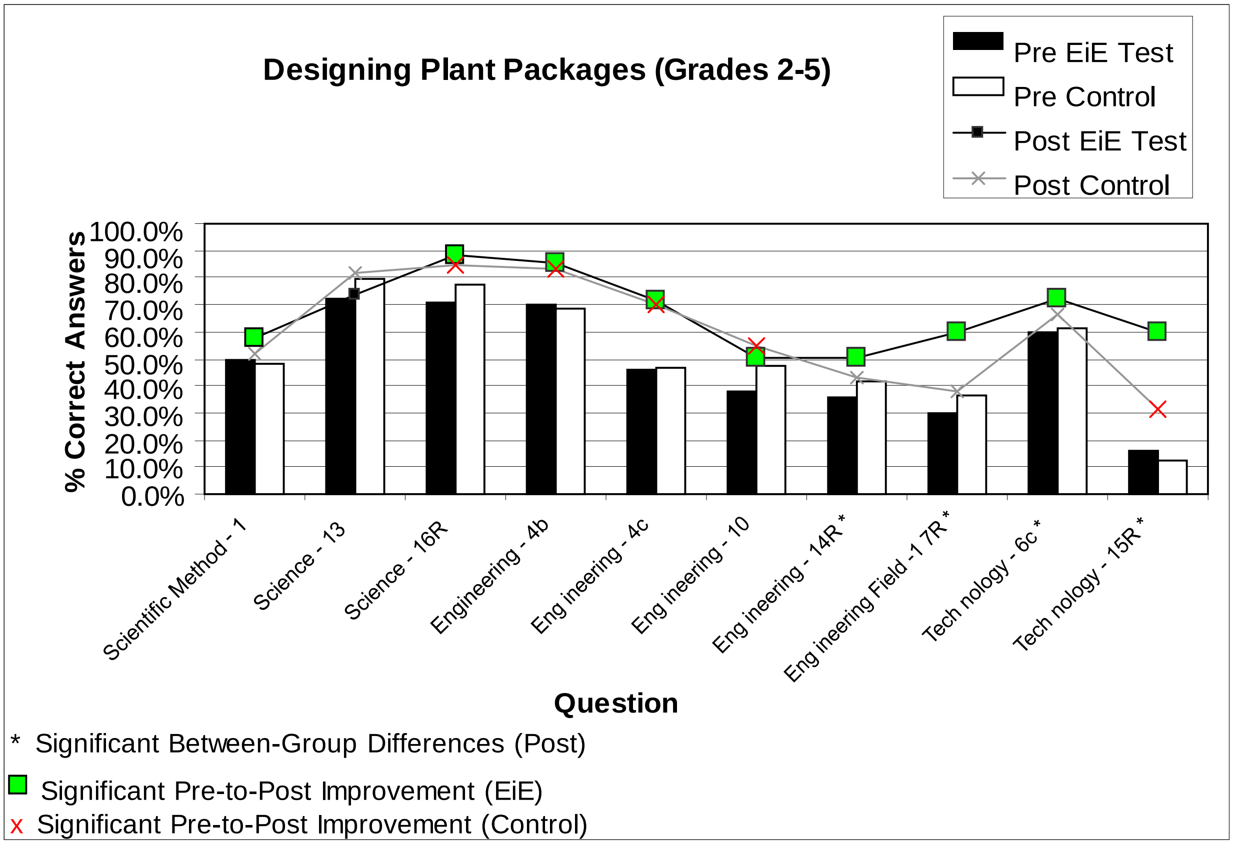
Changing Students' Engineering and Science Knowledge

Teachers seemed convinced that with the engineering units their students were learning not only engineering but also and were learning science better when it was reinforced by science than when it was taught on its own. Next we sought to measure student outcomes. During the development, pilot testing, and field testing of each EiE unit, students in grades 2-5 engaged in a unit complete a pre- and post-assessment specific to that unit. Some questions measure general engineering and technology concepts. Assessment questions are also specific to the engineering field of focus in that unit, engineering and technology concepts that are taught in the unit, and understanding of the relevant science concepts that are reinforced by engineering activities. These assessments demonstrated that EiE students were making significant gains in their science and engineering knowledge.

More recently, we have begun to compare students' EiE learning to a control group of students who have studied the science concepts but not the engineering. Early data indicate that students who engage with engineering and science learn significantly more about engineering and technology than their peers who study only the science. Less expected and therefore more interesting are the data that indicate that students studying engineering and science learn significantly more science about science than students who study only the science. This was true for both genders and all racial/ethnic groups. Finally, there is evidence that for students who engage with EiE, the achievement gap that is present between low socioeconomic and high socioeconomic students (as gauged by participation in the free and reduced lunch program) on pre-assessments is narrowed by the post-assessment. A sample of data and results from national field testing of three units follows. Data are from approximately 1000 EiE (test) students and 500 control students in five states.

<u>Plants and Package Engineering</u>

Analysis of students' completed assessments for *Package Engineering: Designing a Plant Package* (see instrument in Appendix) resulted in several significant and notable findings. EiE (test) students performed significantly better on the post-assessment than control students, and showed significantly more improvement from the pre- to the post-assessment. EiE student improvements on the technology/engineering questions were particularly dramatic. EiE students did significantly better than control on most of the science questions as well, but the performance of test and control was much more similar in these cases—not surprisingly, since both test and control groups received science instruction.



The performance of girls and boys was indistinguishable on the pre-assessment, and nearly so on the post-assessment—girls did better than boys on two technology questions that involved the most reading and complex reasoning. Low-SES students performed significantly worse than higher-SES students on the pre-assessment, but both groups improved significantly on nearly all questions, and by the post-assessment the performance gaps between the two groups were either completely erased or diminished for all questions but one. The *Package Engineering: Designing a Plant Package* unit successfully improved students knowledge of technology, engineering, and science for girls and boys, and for students of higher and lower economic status.

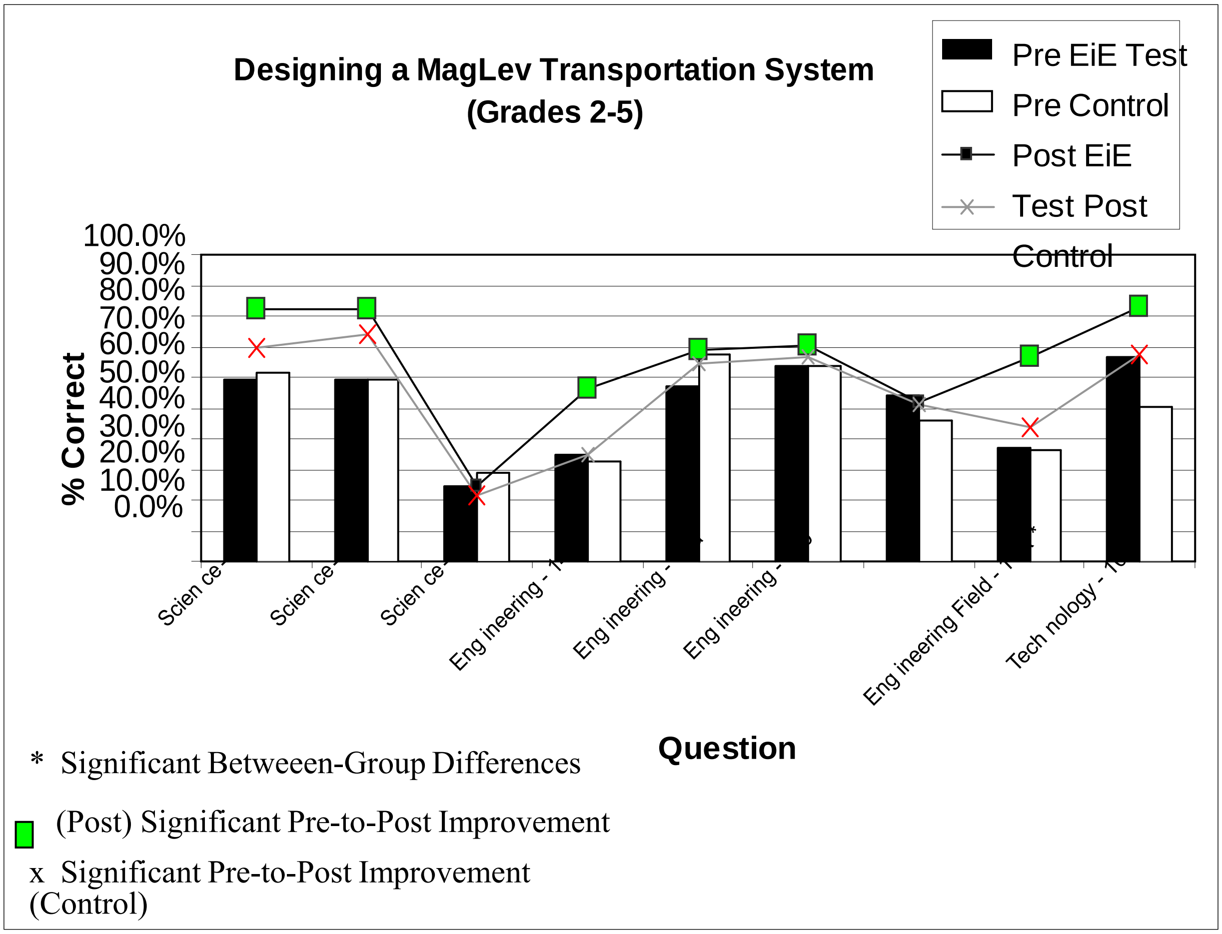
Magnets and Transportation Engineering

The *Designing a MagLev Transportation System* assessment consists of nine questions: three science questions, three data analysis questions (testing math skills), and three engineering/technology questions (see instrument in Appendix). EiE (test) students performed significantly and dramatically better than control on all of the engineering/technology questions, as well as two of the science questions. They also performed significantly better than control on two data analysis questions, but the difference was less pronounced. They did not perform better than control on two of the questions (one data analysis question and one science question). (See figure on next page.)

There were only two significant differences between male and female EiE students on the pre-assessment: girls did better than boys on the hardest data analysis question, and boys did better than girls on an easier data analysis question. Both boys and girls significantly improved on all but one of the questions where the EiE sample as a whole improved—girls improved (but not significantly) on the third data analysis question. On the post-assessment, boys' and girls' performance was almost indistinguishable, with only one question where boys did better than girls (again on a data analysis question).

Students not receiving free or reduced lunch (higher-SES) did better on the pre-assessment than students receiving free or reduced lunch (low-SES) on most questions, but the difference was significant on only one of the questions. Low-SES students improved significantly on six questions while higher-SES students improved significantly on seven questions; both groups regressed on one question (the difference from pre- to post- was barely significant in both cases). Higher-SES students did significantly better than low-SES students on three questions; the reverse was true on one question, indicating a general trend of maintaining the status quo.

EiE students clearly learned about technology, engineering, and the science of magnetism from the *Designing a Maglev Transportation System* curriculum unit. EiE (test) students performed significantly better than control on all engineering/technology questions and most science and data analysis questions. The performance of girls and boys in the test sample was very similar; higher-SES students tended to do slightly better than low-SES students on both the pre- and post-assessments, but the difference was slight, and both groups improved significantly.



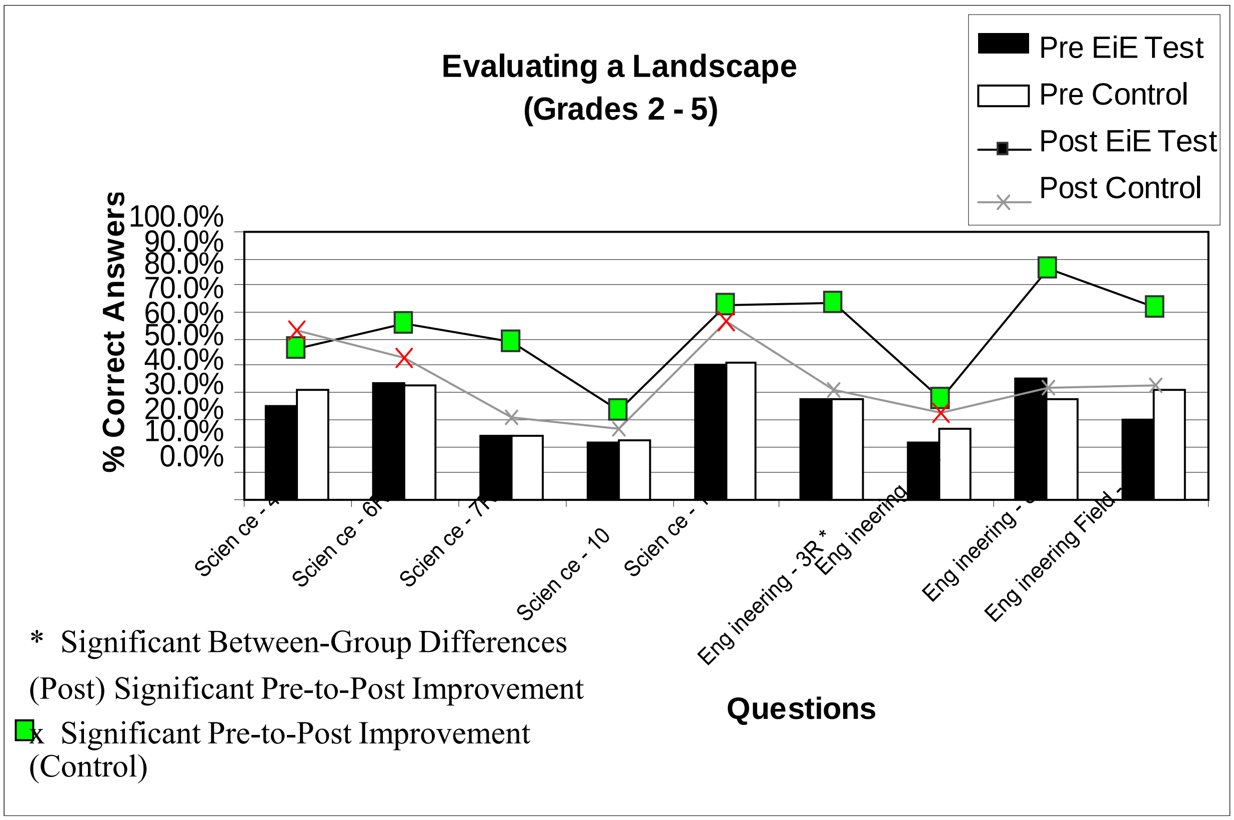
Landforms and Geotechnical Engineering

Analysis of students' completed assessments for *Geotechnical Engineering: Evaluating a Landscape* resulted in several significant and notable findings. Comparing students in the EiE (test) group with their control counterparts, we found that there were no significant differences between the two groups' performances on the pre-assessments. However the EiE group did better than the control group on all post-assessment questions, and significantly better on most questions. EiE (test) students improved significantly on every question on the assessment—both questions about engineering and technology, and questions about the science of landforms. Control students did not improve significantly on any question. (See figure on next page.)

Comparing male and female EiE students, both genders showed significant pre-to-post assessment improvements. Girls performed significantly better than boys on one question on the pre-assessment, and boys significantly out-performed girls on three post-assessment questions. These between-gender differences were small in magnitude.

Students who did not receive free or reduced lunch (the higher-SES students) significantly out-performed students receiving free or reduced lunch (the low-SES students) on three pre-assessment questions. Higher-SES students improved significantly on all questions; low-SES students also improved on all questions, though the improvement was not significant on three of the questions—probably largely because, with only a quarter the sample size, significance is more difficult to measure for the low-SES students. Between the two groups, their performance on the post-assessment was very similar: low-SES were just as likely to correctly answer every question but one—therefore the gap between the two groups was narrowed.

The EiE unit *Evaluating a Landscape* clearly improves students' understanding of engineering, technology, and the science of landforms. Both girls and boys improved on the assessments, as did both low-SES and higher-SES students. The gap between low-SES and higher-SES students on the pre-assessment was narrowed (and nearly eliminated) by the time they completed the post-assessment.



Next Steps, and Future Questions

So far, the EiE team has been pleasantly surprised by the outcomes of our engineering curriculum. We set out to expand teachers' and students' understanding of technology and engineering by engaging them in the processes that ground them. These early results from participants suggest that the curriculum may play a powerful role, serving as a tool to help teachers reconsider how they teach, what they teach, and who is capable of learning engineering. Reports from teachers and students indicate that all types of children are more engaged and our data suggests that children are learning more about science when they are able to do science with engineering. There are probably a number of factors that contribute to such outcomes. Most likely, the structure of the engineering curriculum is one important one. Choosing real-world, relevant problems with no single correct answer invites teachers and students to engage with a problem-solving process. As they work toward possible solutions, students apply their science, engineering, and sometimes language arts and social studies knowledge.

Development and implementation of such project-based, cross-curricular program confront a number of challenges in our current educational setting. Factoid-based standardized tests have created a climate that is not welcoming to such integrated initiatives. Designing materials for national use is particularly difficult without a standard national framework for curricular topics. We do have some national standards documents for science, mathematics, and other topics. However, whether and how states implemented those standards and at which grade level differs among the 50 states, and even among districts and between schools within a state. Thus across the country, students may learn about the life cycle of a plant in first, second, third, fourth, or fifth grade. It's hard to produce materials that integrate with science (or mathematics) topics when they might be taught in any grade and with students with such a range of developmental and cognitive abilities. Integrating engineering with one topic (in our case, science) has been challenging. Even more difficult, however, is producing materials that connect the science AND mathematics that children are learning at any given time with engineering. This is a curricular challenge that EiE is just beginning to explore.

Our work strongly suggests that children benefit by connecting what the topics they study—with each other and with the world around them. As materials developers, professional development providers, and teachers we will need to think carefully about how to foster such interdisciplinary work in our educational systems.

The EiE project is just beginning to collect assessment results. We will continue to engage in much more research. We need to understand whether these results can be scaled as our data to date are from teachers who have self-selected into professional development. We want to examine the role of professional development and parse out which attributes of professional development and implementation contribute to changes in instructional practice. The potential power of elementary engineering as a tool that might foster inquiry-based learning in science, mathematics, and engineering first among teachers and ultimately among their pupils deserves additional investigation. As a "new" subject that they have never studied or seen modeled, engineering seems to create a different type of space for professional development learning. Finally, we need to engage in many more qualitative studies to get a detailed look at what children can know about engineering, when, which children engage and why, and how to scaffold such learning.

References:

[1] G. Wiggins and J. McTighe, *Understanding by design*. Upper Saddle River, NY: Merrill Prentice Hall, 1998.

[2] R. Carson and P. B. Campbell, "Museum of Science: Engineering is Elementary; Exploring the Impact of EiE on Participating Teachers," Campbell-Kibler Associates, Inc., Groton, MA September, 2007 2007.

[3] R. Faux, "Evaluation of the Museum of Science PCET Project," Davis Square Research Associates, Somerville, AM September 8, 2008 2008.

5/12/2008

Engineering is Elementary

"Designing Plant Packaging" Unit Assessment

Today the date is:

MONTH	DAY		YEAR
January			2006
February			2007
March	0	0	2008
April	1	1	2009
May	2	2	2010
June	3	3	2011
July		4	2012
August		5	
September		6	
October		7	
November		8	
December		9	

My initials:

FIRST	MIDDLE	LAST
A–Z	A–Z	A–Z

I am a:

- Girl
- Boy

I was born in:

MONTH BORN: January, February, March, April, May, June, July, August, September, October, November, December

Do Not Mark (0–9) **Do Not Mark** (0–9)

Marking Instructions

- Use a No. 2 pencil or a blue or black ink pen only.
- Do not use pens with ink that soaks through the paper.
- Make solid marks that fill the response completely.
- Make no stray marks on this form.

CORRECT: ● INCORRECT: ⊘⊠◒◔

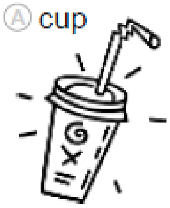
For each question, mark the **BEST** answer.

1. A plant is wilted. What would be the BEST way to make it healthier?

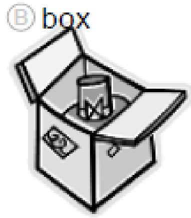
Ⓐ Give it water.
Ⓑ Put it in the sun.
Ⓒ Pollinate it.
Ⓓ Take a few leaves off.

2. Which of these is a package?

Ⓐ cup



Ⓑ box



Ⓒ bottle

Ⓓ these are ALL packages

3. Chen wants to improve the packages for the toys he is selling so that they are better for the environment. Which of these is NOT something he might do to meet his goal?

Ⓐ Change the shape of the packages to use less material.

Ⓑ Reuse other packaging material.

Ⓒ Put more padding inside the packages to keep the toys safer.

Ⓓ Make them from a recyclable material.

4. **For each of the plant structures listed below, mark the function it serves BEST.**

Root	Stem	Leaves	Flower
Ⓐ Making food	Ⓐ Making food	Ⓐ Making food	Ⓐ Making food
Ⓑ Making new plants	Ⓑ Making new plants	Ⓑ Making new plants	Ⓑ Making new plants
Ⓒ Absorbing water	Ⓒ Absorbing water	Ⓒ Absorbing water	Ⓒ Absorbing water
Ⓓ Supporting the plant	Ⓓ Supporting the plant	Ⓓ Supporting the plant	Ⓓ Supporting the plant

5. **Julie bought a new plant. She is not sure how much light or water the plant needs. What would be the BEST thing for her to do to figure it out?**

Ⓐ Give the plant a bit of sun and water. Watch it for a few days to see if it stays healthy.

Ⓑ Put the plant outside in her yard, where the sun will shine on it and rain will fall on it.

Ⓒ Put the plant in the sunniest place in her room and water it every day.

Ⓓ Give the plant lots of extra nutrients.

6. **You baked some cookies, and now you need to bring them to school to sell at a bake sale. Which package would make the least amount of trash?**

Ⓐ A re-usable plastic cookie jar

Ⓑ A shopping bag carrying the cookies wrapped in tin foil

Ⓒ A shoe box carrying each cookie separately wrapped in plastic wrap

Ⓓ A paper plate

7. **A farmer is deciding what package to use to ship apples from his orchard to a bakery for making pies. Which property of the shipping package is probably LEAST important?**

Ⓐ if the package material is sturdy enough to support lots of apples.

Ⓑ if the outside of the package is eye-catching for consumers.

Ⓒ if the package has compartments for apples so they won't get bruised.

Ⓓ if the package is easy to lift and carry.

8. **Which of the following things does a plant need in order to grow?**

Ⓐ nutrients

Ⓑ air

Ⓒ sunlight

Ⓓ ALL of these

9. **What does a packaging engineer need to consider when designing a package for a product?**

Ⓐ the size and shape of the product

Ⓑ the material the product is made of

Ⓒ how the consumer will learn about the product

Ⓓ ALL of these

5/12/2008

Engineering is Elementary

"Designing MagLev Systems" Assessment

Today the date is:

MONTH	DAY		YEAR
January			2006
February			2007
March	0	0	2008
April	1	1	2009
May	2	2	2010
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November		8	
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B	B	B
C	C	C
D	D	D
E	E	E
F	F	F
G	G	G
H	H	H
I	I	I
J	J	J
K	K	K
L	L	L
M	M	M
N	N	N
O	O	O
P	P	P
Q	Q	Q
R	R	R
S	S	S
T	T	T
U	U	U
V	V	V
W	W	W
X	X	X
Y	Y	Y
Z	Z	Z

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Do Not Mark

0	0	0	0	0	0
1	1	1	1	1	1
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4	4	4	4	4	4
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6	6	6	6	6	6
7	7	7	7	7	7
8	8	8	8	8	8
9	9	9	9	9	9

Do Not Mark

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6	6	6	6	6
7	7	7	7	7
8	8	8	8	8
9	9	9	9	9

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CORRECT: ● INCORRECT: ✓ ✗ ◒ ◔

Mark the **BEST** answer for each of these questions.

1. Samir is a transportation engineer. What would he NOT do for his job?

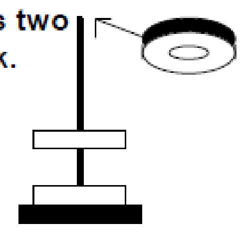
Ⓐ Figure out how to make a highway safer.

Ⓑ Drive trains.

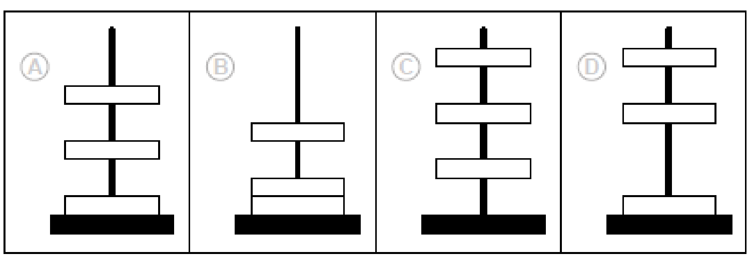
Ⓒ Improve the efficiency of a subway system.

Ⓓ Recommend the location of a crosswalk.

2. The diagram on the right shows two ring magnets stacked on a stick.



Which diagram below shows what might happen if another magnet is added to the top?



3. Cherise stacked two ring magnets on a stick so they repelled each other. How could she DECREASE the magnetic force between them?

Ⓐ by putting cardboard between the magnets

Ⓑ by pulling the magnets apart

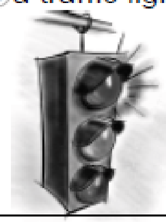
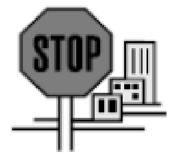
Ⓒ by wrapping one of the magnets in plastic wrap

Ⓓ any of the above

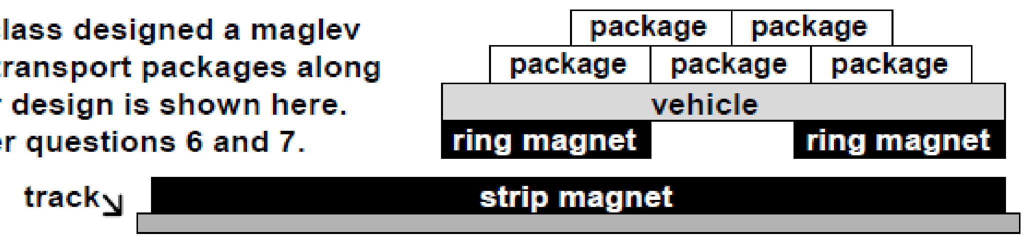
4. **Below, mark the diagram in which the magnets shown will repel each other.**

(A)	(B)	(C)	(D)
		S N	N S
N S N S	S N S N	S N	S N

5. **Which of these is a technology designed to keep people safe at an intersection?**

(A) a crosswalk	(B) a traffic light	(C) a stop sign	(D) all of these.
			

A group of students in a class designed a maglev transportation system to transport packages along a track. A diagram of their design is shown here. Use the diagram to answer questions 6 and 7.



6. **The system was working well when the students tried to transport 5 packages, but when they tried to transport 6 packages, the vehicle didn't levitate anymore. Which of the following changes to their system would NOT help them carry more packages?**

(A) Add magnets to the track to increase the force of repulsion.

(B) Flip the poles of the magnets on the track.

(C) Replace the magnets on the vehicle with magnets that are not as heavy.

(D) Replace the magnets on the vehicle with stronger magnets.

7. **The class decided to collect some data about how their maglev system was working with different numbers of magnets. The data are shown in the table to the right.**

Design	A	B	C	D
Number of magnets on the vehicle	1	2	1	2
Number of magnets on the track	1	1	2	2
Number of packages the vehicle can carry	5	6	7	8

Below, mark each statement TRUE or FALSE.

	T	F
The vehicle can carry more packages if more magnets are added to the vehicle.	(T)	(F)
The vehicle can carry more packages if more magnets are added to the track.	(T)	(F)
To carry more packages, it is better to add an extra magnet to the track than to the vehicle.	(T)	(F)

3/26/2008

Engineering is Elementary

"Evaluating a Landscape" Assessment

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J	J	J
K	K	K
L	L	L
M	M	M
N	N	N
O	O	O
P	P	P
Q	Q	Q
R	R	R
S	S	S
T	T	T
U	U	U
V	V	V
W	W	W
X	X	X
Y	Y	Y
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CORRECT: ● INCORRECT: ✓ ☒ ◒ ◔

For each question, mark the **BEST** answer.

1. Cathy is a geotechnical engineer. What might Cathy do for her job?

Ⓐ Test the properties of soil.

Ⓑ Build a stone wall for a garden.

Ⓒ Design batteries.

Ⓓ All of the above.

2. Jay is an engineer working on designing a building in an area that has earthquakes. What is LEAST important for Jay to consider when he is designing the foundation for the building?

Ⓐ soil type

Ⓑ soil compaction

Ⓒ age of the soil

Ⓓ thickness of soil layers

3. Which of the following would cause the SLOWEST change in the shape of a mountain?

Ⓐ an avalanche

Ⓑ an earthquake

Ⓒ erosion due to wind

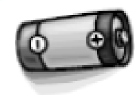
Ⓓ a landslide

4. **Which of these things is NOT a model that an engineer could use in her work?**

(A) map of hiking trails 

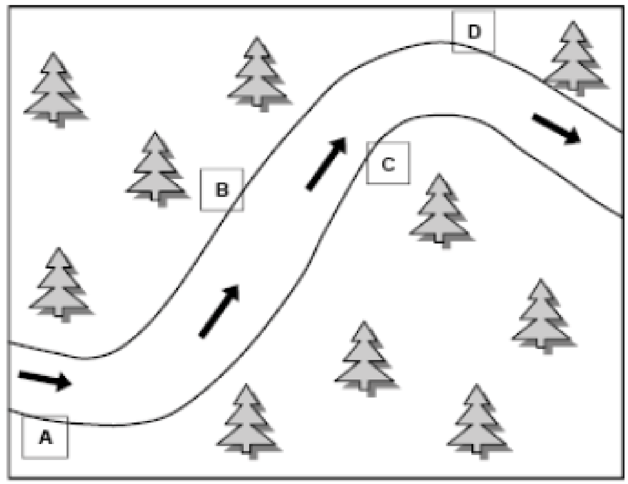
(B) globe 

(C) miniature bridge 

(D) battery 

Below is a map of a river with several sites marked along the riverbank. The arrows show which way the river flows.

Look at the map and answer questions 6 and 7.



5. **Which site is MOST likely to erode?**

(A) site A (B) site B (C) site C (D) site D

6. **Which site is LEAST likely to erode?**

(A) site A (B) site B (C) site C (D) site D

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7. **Luisa is a geotechnical engineer working with villagers in Nepal. She is choosing a site for the foundation of a small bridge. Look at the properties described below, and mark the BEST site for building the bridge foundation.**

Site	Property 1	Property 2
(A) Site 1	On a curve of the river	Compacted rocky soil
(B) Site 2	On a straight part of the river	Compacted rocky soil
(C) Site 3	On a curve of the river	Far from where the villagers want the bridge
(D) Site 4	Loose organic soil	Near where the villagers want the bridge

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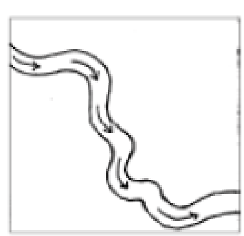
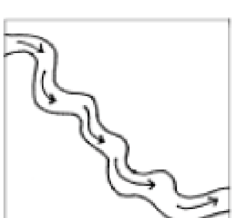
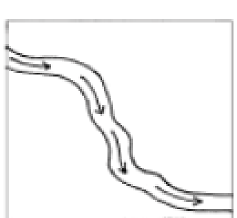
8. **To the right is an aerial map showing the course of a river. The arrows indicate the direction that the river is flowing.**

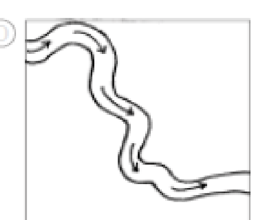
Which of the pictures below MOST LIKELY shows what the course of the same river will look like in 50 years?



(A) 

(B) 

(C) 

(D) 

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

Deborah Hecht, Maria Russo, and Bert Flugman

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**		
	Mean Pre	Mean Post	Mean Difference	Mean Pre	Mean Post	Mean Difference	Inf.	Comp	Diff.

	Infusion Classes (N = 454)			Comparison Classes (N= 319)			Infusion v. Comparison		
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 8th 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.

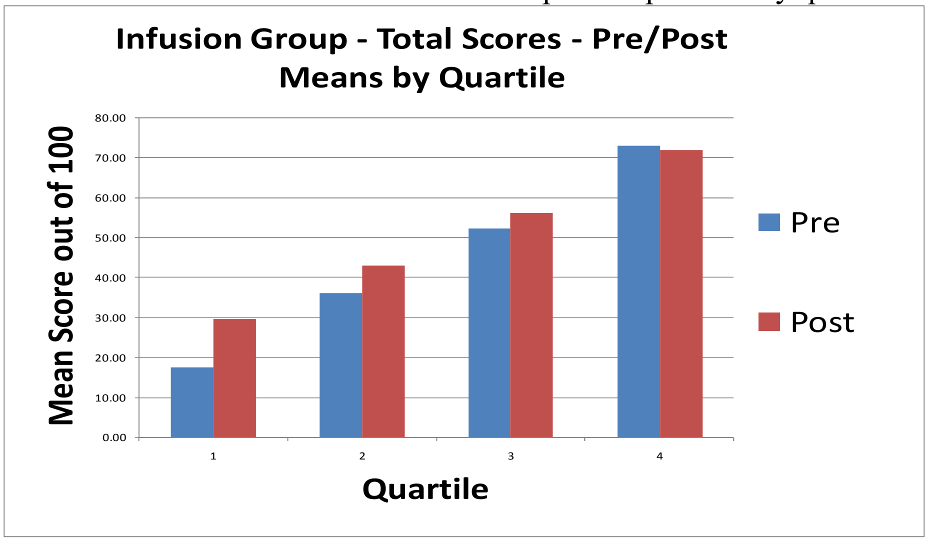
<u>Math Infusion in Engineering/Technology Education:</u> The study of the math infused technology lesson, as with the science intervention, examined changes in student math content knowledge and student attitudes. The content knowledge assessment included both multiple choice and open-ended (rubric 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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Challenges in Mathematics Education and the Interaction with Science Education

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The need to improve the teaching and learning of mathematics and science, K-16, and the interaction between the two domains has been a focus of attention over my entire career—and I am no spring chicken! Within the two areas of disciplinary research and research on teaching and learning in the discipline, we have different cultures, different language for describing our work, different research methodologies, and fundamentally different domains of knowledge. Proof is the mainstay of the mathematical enterprise– reasoned argument that can be put forward, logically examined, and admitted into the mathematical working space for building more mathematics. Science is an experimental science–not devoid of reasoned argument, but argument that is based on experimental results that have accumulated to the point of having explanatory power. Mathematics is used in science and in most other domains of scholarly work. New areas of mathematics, such as mathematical biology and other areas where mathematical modeling can be a tool are examples of where the disciplines have come together. The question is whether we can find ways to make such examples salient to students in K–12 and university classrooms. I am not a scientist, but in hanging around with scientists during my career, I have come to believe that finding ways to support students learning of both is the responsibility of us all and has the potential to enhance each discipline. However, I am skeptical about making any rapid progress at integration.

Mathematicians in the US have become active players in mathematics education in unprecedented ways in the past couple of decades. Mathematics educators and mathematicians have very different commitments to the enterprise and these interactions are not always easy. However, this interaction between mathematicians and mathematics educators is one of the best hopes for improving mathematics education in the 21st century as difficult (and as stimulating) as these interactions are at times. Again, here science seems different. There are current examples of scientists who have dedicated their energy to science education experiments over long periods of time and, as a result of these experiments, have developed better materials for learning science at the school and university level. These experiments have also added to the science literature on student's learning of science. Focusing on student's thinking and reasoning in these experiments have revealed much about what is hard for students to make sense of in science. We have examples of such work in mathematics education as well. I would put the work of Jere Confrey, Paul Cobb, Judith Sowder, James Kaput and many others in mathematics education in this camp of helping to articulate how students learn and student learning challenges in ways that give us grist with which to improve mathematics materials and the teaching and learning of mathematics. Of course, as we all know, these areas of learning difficulty in mathematics or in science are very challenging to improve.

I have given much thought to what my contributions can be to this conference and have decided to focus my remarks in two areas. The first is on my own work and the second is on challenges we face in future work to improve mathematics teaching and learning. I expect that many of the challenges I see are also challenges for science education. First I will share relevant aspects of the work in which my research and development group and I have engaged for over 30 years. Many of these remarks are based on papers that we have published about our work.

Curriculum Materials as an Intervention

The human players physically present in a classroom are of course the teacher and the students. But whatever the subject, teachers use materials—in mathematics, mostly text materials—to engage students in learning. However, in my career, there have only been two large-scale national attempts to improve text materials in mathematics. The first was stimulated by the Russian launch of Sputnik which led to the National Science Foundation (NSF) funding a number of large-scale projects called the "new math". The Principle Investigators of most of these projects were mathematicians. Beautiful mathematics was incorporated into these materials and massive amounts of money was spent on retooling mathematics and science teachers through year long and summer long institutes. The huge investment in these projects was considered to be an appropriate national response to the technological advantage the Russians seemed to have over the US. The goal was to produce more mathematicians through improving students' engagement with mathematics in K-12 education. This activity brought a storm of criticism to NSF's door. The complaints from the public were vicious and the Education Directorate at NSF became a shadow of its former self—reduced to an Office from a Directorate. However, in 1989, the document, *Curriculum and Evaluation Standards for School Mathematics* was published by the National Council of Teachers of Mathematics (NCTM) and the national mood changed.

For the first time, the nation had a set of standards for what mathematics should be learned and over what grade bands. This spurred the argument that there were few if any existing materials that would help teachers reach these standards with their students. NSF once again funded a set of materials development projects for elementary, middle and high school mathematics. There was one significant change in the thinking at NSF. This time, author teams were required to sign with a commercial publisher by the end of the second year of the projects. This was to ensure that the materials created would have a way to reach teachers in all states and territories. My research and development group—William Fitzgerald, Elizabeth Phillips, James Fey, Susan Friel and I—came together to create a proposal that was funded in 1991. As you may know, these projects were funded to do a revision in 2000 to incorporate what had been learned from the fields' six year engagement with the materials and from the NCTM update of the Standards, *Principles and Standards for School Mathematics.* In the next section, I will articulate the goals and stances of our curriculum development group since these seem relevant to finding ways in which science and mathematics can support each other.

The Case of Connected Mathematics [1]

The Connected Mathematics Project (CMP) authors began the work by using the help of our advisory board to articulate the goals for what a student exiting from CMP in grade eight would

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[1] This section (the Case of Connected Mathematics) is based on a chapter in the book *Perspectives on the Design and Development of School Mathematics Curriculum,* published by NCTM in 2007.

know and be able to do in each of the strand of mathematics—number, algebra, geometry, measurement, probability and statistics and in the interactions among strands. These essays became our touchstones for the development of the materials for three grades—6, 7, and 8. Our driving goal of CMP was to help students and teachers develop mathematical knowledge, understanding and skill along with as awareness of and appreciation for the rich connections among mathematical strand and between mathematics and other disciplines (Lappan 2006, p. 2). The mathematical standard that has been a guide for us in our work is the following:

> All students should be able to reason and communicate proficiently in mathematics. They should have the knowledge of and skill in the use of the vocabulary, forms of representation, materials, tools, techniques, and intellectual methods of the discipline of mathematics, including the ability to define and solve problems with reason, insight, inventiveness, and technical proficiency (Lappan 2006, p 2).

Our statement was written prior to the publication of the National Academy of Science, "Adding It Up" (NRC 2001). However, the stance of this National Research Council (NRC) publication's five interrelated strands that, together, comprise proficiency is echoed in this personal standard for our work. The first four NRC strands are conceptual understanding, procedural fluency, strategic competence (the ability to formulate, represent, and solve mathematical problems), and adaptive reasoning (the capacity to think logically and to informally and formally justify one's reasoning). The fifth strand, productive disposition, is "the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that steady effort in learning mathematics pays off, and to see oneself as an effective learner and doer of mathematics" (NRC, 2001, p. 131).

Principles that Guided the Development of Connected Mathematics

The following statements reflect both research and policy stances in mathematics education about what works to support students' learning of important mathematics to higher levels than we have accomplished in the United States in the past.

- An effective curriculum has coherence—a key idea is identified and the underlying concepts and related skills and procedures supporting the development of this idea are identified and included in an appropriate development sequence of problems/activities.

- Classroom instruction focuses on inquiry and investigation of mathematical ideas embedded in rich problem situations.

- The key mathematical goals are elaborated, exemplified, and connected through the problems in an investigation.

- Both conceptual and procedural knowledge are developed with the underlying assumption that the interaction of conceptual and procedural knowledge is what produces fluency.

- Important mathematics ideas are explored through appropriate tasks in the depth necessary to allow students to make sense of the mathematics.

- To reason effectively in mathematics requires facility with forms of representation of ideas and the skill to move flexibly among these representations--graphic, numeric, symbolic, and verbal forms.

- The information-processing capabilities of calculators and computers are used to make fundamental changes in the way students learn mathematics and apply their knowledge in solving problems.

Rationale for a Problem-Centered Curriculum

Connected Mathematics is different from more conventional curricula in that it is problem-centered. This section elaborates what we mean by this and what the value added is for students of such a curriculum. The beginning quote from a CMP teacher sets the scene for examining the curriculum.

> During that semester of student teaching, I worked with a group of 8^{th}-grade students. There was one experience with the unit *Moving Straight Ahead* (Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998) that stands out in my memory. As an introduction to an investigation, students looked at graphs of linear relationships, one of which was of the equation $y=300 + 2x$. With its graph on the overhead and pointing to the y-intercept, I asked the students, "What is this?" I expected students to identify the y-intercept. Instead students said, "That is the starting or initial amount." I slowly thought to myself, "Yeah…yeah, that's right!" That was exactly right. Until that minute I had never made the connection between the graphical representation of the y-intercept and the situation it represented. In my mathematical experience, I have been taught to look at tables, graphs and equations. "Story problems" were rarely assigned. Even when I was asked to look at all representations, I was not pushed to understand the connections between them. For me, algebra had been about following a set of rules. It was not about understanding patterns of change and how those were reflected in other representations (Porath, 2008 pp. 211-212).

The tasks or problems in which students engage form the perceptions they have about a discipline. For example, if students in a geometry course are asked to memorize definitions, they think geometry is about memorizing definitions. If students spend a majority of their mathematics time practicing paper-and-pencil computations, they come to believe that mathematics is about calculating answers to arithmetic exercises as quickly as possible. As a result they may not be able to recognize and apply these skills to other situations.

Formal mathematics begins with undefined terms, axioms, and definitions and deduces important conclusions logically from those starting points. However, mathematics itself is produced and used in a much more complex combination of exploration, experience-based intuition, and reflection. To be able to develop the skills to solve "new" problems, students need to spend significant portions of their mathematics time solving problems that require thinking, planning, reasoning, computing, and evaluating. (Lappan et al. 2007).

Criteria for a Mathematics Task

We have said that a good task is one that supports some or all of the following:

- The problem has important, useful mathematics embedded in it.
- Students can approach the problem in multiple ways using different solution strategies.
- The problem has various solutions or allows different decisions or positions to be taken and defended.
- The problem encourages student engagement and discourse.
- The problem requires higher-level thinking and problem solving.
- The problem contributes to the conceptual development of students.
- The problem connects to other important mathematical ideas.
- The problem promotes the skillful use of mathematics.
- The problem provides opportunity to practice important skills.
- The problem creates an opportunity for the teacher to assess what his or her students are learning and where they are experiencing difficulty.
-

Fluency with Concepts and Related Skills and Algorithms

Students need to practice using new mathematics concepts, ideas and procedures to reach a level of fluency that allows them to "think" with the ideas in new situations. The following principles relate to our review of skills practice.

- Immediate practice is related to the situations in which the ideas have been developed and learned.
- Continued practice uses skill and procedures in situations that connect to ideas that students have already encountered.

- Students use the ideas and skills in situations that extend beyond familiar situations.

- Practice is distributed over time to allow ideas, concepts and procedures to reach a level of fluency of use in familiar and unfamiliar situations and to allow connections to be made to other concepts and procedures.

- Students reflect on what they are learning, how the ideas fit together, and how to make judgments about what is helpful in which kinds of situations.

- Students learn how to make judgments about what operation or combination of operations or representations is useful in a given situation, as well as, become skillful at carrying out the needed computation(s). Knowing *how to*, but not *when to*, is insufficient.

Issues Faced in Developing the Curriculum

As we set out to write a complete connected curriculum for grades, 6, 7, and 8, the following issues quickly surfaced:

- What are the overarching goals in each strand?

- What size of problem is feasible for the teacher and students to explore?

- What kind of sequencing or scaffolding is needed?

- How much help is needed to move from a contextual setting to a symbolic situation free of context?

- What basic skills should be developed and how?

- When is group or individual work appropriate?

- What kinds of practice or homework and reflection are needed to ensure some degree of automaticity of understanding?

- What assessment is appropriate?

- How much help with the mathematics and pedagogy does a teacher need?

There were no easy answers to these questions. Even though it took classroom trials and observations, discussions, revisions, more trials, and research and reflections to resolve such issues into a coherent curriculum, our initial analysis of overarching goals remained sound. However, our notions of what we could expect to teach in one year, in a curriculum based on bigger problems, did change. Sufficient instruction time was needed to foster deep understanding of the big ideas.

A Curriculum for Teachers and Students

Jerome Bruner in *The Process of Education* wrote,

> If it (new curriculum) cannot change, move, perturb, inform teachers, it will have no effect on those they teach. It must first and foremost be a curriculum for teachers. If it has any effect on pupils, it will have it by virtue of having an effect on teachers. (p. xv)

If students' development of deep, connected mathematical understanding and skill is the primary goal, then the ways in which *students engage with mathematics* and the *instructional practices of the teacher* must support this goal. We have taken a stand that curriculum and instruction are not distinct. The circumstances in which students learn effects what is learned. The "what to teach" and the "how to teach it" are inextricably linked. The principles that guided us in the development of the materials for students provide a way of raising issues and questions about what kind of teaching and learning is implicit in these stances.

Goals for Students

Students develop deep understanding of mathematical concepts, skills, procedures, and processes through:

- solving problems,
- observing patterns and relationships among variables in a situation,
- conjecturing, testing, discussing, verbalizing, and generalizing these patterns,
- discovering salient mathematical features of patterns and relationships and abstracting the underlying mathematical concepts, processes, and relationships,
- developing a mathematical language for representing and communicating ideas, and
- making sense of and connecting mathematics abstracted from their experiences.

Taking this stance on how students learn mathematics leads immediately to the need to examine what teaching practices will support such engagement. The development of materials was guided by key instructional themes. These themes are tied to the content and process goals, but point more directly to the nature of classroom discourse needed to support the growth of student understanding and skill.

Instructional Themes

- *Teaching for Understanding:* The curriculum is organized into modules around mathematical "big ideas," clusters of important, related mathematical concepts, processes, ways of thinking, skills, and problem solving strategies, which are studied in depth with the development of conceptual understanding and computational fluency as the goals.

- *Connections:* The curriculum emphasizes connections among mathematical topics and between mathematics and other school subjects.

- *Mathematical Investigations:* Instruction emphasizes inquiry and discovery of mathematical ideas through investigation of rich problem situations.

- *Representations:* Students are supported in learning to reason effectively with information represented in graphic, numeric, symbolic, and verbal forms and move flexibly among these representations.

- *Technology:* Teaching approaches are formulated to make use of the information processing capabilities of calculators and computers to aide the learning of mathematics and the development of mathematical problem solving skill.

These five instructional themes and the goals for student engagement indicate how the philosophy of CMP is compatible with major shifts in teaching and learning mathematics as described by the NCTM in the *Professional Standards* and in the *Principles and Standards for School Mathematics.*

We have worked to provide students with engaging worthwhile problems and to provide teachers with ways to plan and carry out this problem–centered teaching in their classroom. In the teacher's material, we point to the need to reflect, during planning for instruction, on such questions as:

- Is this a good task for my students?
- What mathematical development will it support?
- What questions can I use to help my students engage with the task?
- What questions can I ask to help the students extract, make more explicit, and generalize the embedded mathematics?

This problem-centered curriculum requires that the teacher possesses a broader view of mathematics and a deeper knowledge of pedagogy based on "inquiry."

Developing a Classroom Climate

The materials, for both student and teacher, are designed in ways that help students and teachers build a different pattern of interaction in the classroom. The materials try to support a teacher and the students in building a community of learners who are mutually supportive as they work together to make sense of the mathematics. We do this through the tasks provided, the justification that students are asked to provide on a regular basis, the opportunities for students to talk about and write about their ideas, and the help for the teacher in using alternative forms of assessment and a problem–centered instructional model in the classroom. In the teacher materials, ideas from many teachers are included to help establish an environment that supports students taking more responsibility for making sense of mathematics.

Change is hard for both teachers and students. Teachers may be frustrated in moving from a rule-based curriculum to a problem-centered one. Students may not like their past experiences with mathematics, yet may still resist any attempts of the teacher to change the culture of the classroom. Students may be used to a mathematics classroom where little is required of them beyond practicing the idea that was illustrated by the teacher in the first part of the lesson. In a classroom with a teacher committed to mathematical discourse around interesting problems situations, students, resistant in September, can be fully engaged by January.

The Teaching Model

For over two decades, we have been experimenting with ways to help teachers think about problem-centered teaching. As we developed the student materials and the supporting teacher materials, we took into account the demands of problem-centered teaching. We developed an instructional model that provides a lesson-planning template. This model looks at instruction in three phases—*launching, exploring, and summarizing.*

During the first phase, the teacher *launches* the investigation with the whole class by setting the context for the problem. This involves making sure the students understand the setting or situation in which the problem is posed. More importantly, the problem must be launched in such a way that the mathematical context and challenge are clear. The teacher considers the following: What mathematical question is, or can be, asked in this situation? What are students expected to do? How are they expected to record and report their work? Will they be working individually, in pairs, or groups? What tools are available that might be helpful? This is also the time when, if necessary, the teacher introduces new ideas, clarifies definitions, reviews old concepts, and connects the problem to students' prior knowledge. Launching tasks in such a way that the challenge of the task is left intact even though students are given a clear picture of what is expected is critical. It is easy to tell too much and lower the challenge of the task to something fairly routine.

After the task is launched, students *explore* the task as the teacher circulates; asking focusing questions when a student or group is struggling and extending questions when students have solved the problem but have not generalized or extended the problem as far as possible. The teacher takes stock of who is understanding and who needs help; who has a strategy, generalization, or interesting way of explaining the problem solution that needs to be shared in the summary; and who has a good idea that needs to be shared, but maybe does not have a complete solution. At times an incorrect solution provides a productive class learning opportunity.

The final phase of the instructional model is the *summary*. This is the most important and, perhaps, the hardest phase to do well. Here the students and the teacher work together to make the mathematics of the problem more explicit, to generalize certain situations, to abstract useful mathematical ideas, processes, and concepts, to make connections, and to foreshadow mathematics that is yet to be studied.

As we developed the curriculum, we believed that student writing and explaining would help students clarify their thinking and understanding. In the early drafts of the trial material, we had students writing and explaining constantly! The trial teachers were overwhelmed with the demands of so much writing. It became clear that when students write, there should be a good mathematical reason for that writing; there should be ideas to pull together, clarify, and record for future reference. Out of our struggles with writing prompts, a feature that has become a real strength of the materials for teachers and students evolved. At the end of each collection of related problems, there is a *mathematical reflection*. This is a set of questions designed to help students reflect on what has been learned, why is it important, when is it useful, and how it fits in with prior knowledge. The questions in the reflections point to the big ideas and how they fit together (abstracting and connecting); they point to skills (how-tos); they point to decisions to be made and how one makes them (when-tos); they raise issues about how these problems are similar to and different than problems encountered earlier (connecting, discriminating, and elaborating); and finally, they point toward questions to ask in similar situations (questioning habits). Each unit contains four to seven mathematical reflections that read by themselves tell a mathematical story about the unit, serving as a guide for the teacher and students. Student journals in which they write these reflections become a story of their own mathematical progress.

Challenges We Face after 20 Years of Curriculum Work

We live in a world in which mathematics is required in nearly every job—certainly the ones that provide a decent living for people. This means that we need to raise the mathematical proficiencies of all of our students to new heights. In order to accomplish this, our teacher education programs need to prepare extremely well started beginners.

We need to set new expectations for schools and for the ways teachers work together.
The message needs to be that teachers need a broader curriculum view that they have at present. A third grade teacher needs to know the mathematics of grades two and grade four in his or her school. The attitude that I am a kindergarten teacher so why should I learn all this stuff sells our students short. Building a teaching community in which interaction, common planning and assessments, cross-disciplinary interactions and planning are the norm is needed to help teacher make what amounts to a substantive culture change in their schools.

Consistent focused high quality professional development opportunities are needed. Expecting teachers to work together on planning and debriefing lessons should be the norm in schools. This means that time for such activity is built into the school day. Yes, teachers should be held accountable for student learning. But school administrations, school boards and the community are responsible for building a climate in which teachers are expected to be and are given opportunities to become the instructional voices for the disciplinary knowledge and support students need to thrive. Currently, the role of a teacher in many schools has been undermined to the point that teachers are leaving the profession, or even worse, choosing to give students experiences with particular skills in isolation from each other in order to "cover" what is being tested on the state exam.

Summary

I have tried to give you some insight into the ideas and commitments that have driven my team for 25 years. I have done this in the spirit of opening up a discussion of which ideas and commitments seem relevant in both mathematics and science. The huge movement in standards based mathematics to more contextualized problems opens the door on possible areas of integration between science and mathematics. To make progress in the direction of this conference's major goal will take long term, serious research and development of curricula that promote student engagement in using science contexts in mathematics learning and mathematics contexts in science learning. Perhaps areas of integration that are happening on university campuses can become a test bed for such activity in preparing teachers of mathematics and science with the goal of giving future K-12 students more seamless experiences with the "mathematical sciences". Remember the stance of W.W. Sawyer:

> *The depressing thing about arithmetic badly taught is that it destroys a child's intellect and, to some extent, his/her integrity. Before they are taught arithmetic, children will not give their assent to utter nonsense; afterwards they will. Instead of looking at things and thinking about them, they will make wild guesses in the hopes of pleasing the teacher.*
>
> W. W. Sawyer
> [British mathematician]

The teaching and learning of mathematics and science can open the eyes of our students to the beauty and wonder of our amazing physical and intellectual world. Done badly, it can also kill the spirit of a child, make them feel stupid, and forever condemn them to a physical and intellectual world that stimulates no curiosity.

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What Needs To Be Put Back Into S, T, and E?: Well Chosen M.

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STEM (Science, Technology, Engineering, and Math) is a hot term in national and regional policy and funding circles, likely reflecting a combination of anxiety about poor test scores under NCLB testing and a shrinking and increasingly less qualified technical workforce. While everyone is in favor of STEM (together with mom and apple pie), there is no consensus on what STEM as a construct means. On the one end of the spectrum is simply the idea that all four components of STEM should increase in presence and effectiveness in K-16 settings, in somewhat independent fashion, reflecting the usual silo approach to education practice and policy.

On the other end of the spectrum is the idea that the four components of STEM actually depend upon one another and thus must improve as a cluster. The word 'integration' is typically attached to STEM when that end of the spectrum is being proposed. But there are many possible forms of integration, ranging from pairwise integration (e.g., putting some E into T, or M into S, or S into E) to complete integration of all four (e.g., a course on robotics that introduces students to mechanics (S), systems design (E), circuit boards (T), and differential equations (M)). Given the large structural and training shift that would be required for full integration, it is probably too radical an idea to be implemented in more than just a few occasions in the curriculum. Pairwise integration is going to be much more doable, although not without technical and political challenges.

Where do we stand now on STEM integration in the US? For some time now, we have seen interesting trends at the middle and high school levels:
A number of mathematics curricula have become more application and problem solving oriented, although many of the applications are from business settings rather than science, technology, or engineering, perhaps because those applications are easier to explain.
Science curricula (and engineering science curricula) have become more qualitative and less math oriented. Data is gathered. Tables and graphical representations are created. But patterns and relationships are typically left in qualitative form. Equation generation and reasoning/problem solving with equations are left as optional extension activities.
Technology education and engineering curricula have come to include design, but with little math. Designs may be tested with quantitative measures, but there is rarely mathematical analysis to enable optimization and decision making, critical components of modern technological design.

In other words, in STEM, M has tried to make itself more amenable to TEM, but STE has moved away from M. If one were to examine classroom instruction, I think one would find similar patterns: some Math teachers try to develop new ways of contextualizing mathematics while many STE teachers find new ways to cover STE concepts by using less math.
I argue that curricular design decisions to minimize mathematics is an important component of the generally poor US educational outcomes and that the solution to reversing this disaster will

lie in undoing those decisions. I will note, however, that new methods for integrating mathematics into STE more effectively than they are currently integrated is both positive for education and required if we want to expand our STEM literate workforce.

How did we get here? The choice to avoid mathematics has an underlying rationale. Many children in the US are relatively weak in mathematics (i.e., a low overall mean), which implies that it is not a pre-existing conceptual resource that children bring to the classroom for teachers and curricula writers at particular grade levels to depend upon. In addition, there is huge diversity in math skill across children at any grade level (i.e., a high standard deviation, and sometimes even a bimodality), which can be just as problematic for teachers and curricula writers in selecting the right level of mathematics to include. Sometimes a middling level is used, when in fact few children actually sit at that middle level: the large group of mathematically weak children is left confused and the substantial group of mathematically strong children is left bored.

In an effort to bring more science, engineering, and technology literacy to the mainstream (and to undo the shrinking and relatively male and ethnically homogeneous technical workforce), one can see how math was viewed as a barrier to rather than enabler of learning. But at a global level, the decision to deemphasize mathematics is not helpful to effectively educating the mainstream because math is such a critical part of general literacy in science, technology, and engineering. In addition, avoiding math integration further creates a populace who cannot easily enter the technical workforce because success in that domain depends critically on developing mathematical competency in a variety of mathematical topics.

One might characterize the decision to avoid mathematics as an instance of optimal behavior at a local level producing results that are far from optimal at the global level. That is, in trying to cover any particular set of material in S, T, or E, it was easier to teach the concepts by avoiding the math. But collectively, S, T, and E might have all benefited by contributing to math literacy in later grades. However, I think it might be even worse than that: even at a local level, S, T, and E probably would have obtained better results at each grade level if math had been included (effectively) rather than deemphasized, and that globally the results are a compounded disaster. The remainder of this white paper has three short parts. In the first part, I explain why mathematics is a critical component of science, technology, and engineering even in relatively basic form appropriate for K-12. In the second part, I explain why mathematics is also an enabler of learning even qualitative concepts. In the third part, I discuss the challenges (and possible solutions) to reintegrating mathematics into K-12 science, engineering, and technology education.

Mathematics as Critical to Science, Technology, and Engineering

Mathematics is the language of physical sciences and engineering sciences, and a tool for all sciences. All of the reports from AAAS regarding science education have included a very prominent role of for mathematics (e.g., Science for *All Americans, Benchmarks for Scientific Literacy, Designs for Science Literacy*), each with multiple chapters devoted entirely to mathematics. The *National Science Education Standards* also include mathematics, but not in such a prominent fashion (see Appendix A).

Often theories and laws are fundamentally mathematical abstractions. Many past and current scientific and engineering science inquiries are about which mathematical instantiation of a relationship is in fact found in nature or characterizes a particular designed system. Even the life sciences have these kinds of mathematical form debates (e.g., in psychology, does forgetting follow an exponential or power function of time?). To not understand the distinctions among the mathematical forms is to not understand the question being asked.

In addition, the scientific community frequently expresses itself in terms of mathematics, both at the level of relationships being investigated and at the level of mathematical/statistical transformations being enacted on data to extract out theory-relevant patterns. Thus, being weak in mathematics means being doomed to outsider status, similarly to not knowing how to effectively speak and read English these days dooms many children to outsider status in many elements of modern society.

For students enacting scientific activities, mathematics is also a necessary tool for cleaning up and organizing the data to reveal more clearly the underlying patterns. To avoid this use of mathematics entirely either hides variability from students entirely (creating damaging misconceptions) or hides patterns that were supposed to be found (undermining the very goals of the activity). To script the data analysis activities for students to execute without understanding merely contributes the cultural tea dance view of science process, rather than setting it up properly as a sense-making activity.

Mathematics is also critical to engineering analysis and technological design. A hallmark of modern engineering is the move from design by pragmatic rules-of-thumb and trial-and-error to design via analysis and optimization. The majority of complex technologies and structures developed in the last 50 years could not have been designed without some analysis and optimization. The space of possible design choices is too large, and the range of workable choices given the high performance expectations (e.g., very strong, very cheap, very light, easy to mass produce, …) is very small. We simply would not have found solutions without the use of math to analyze and optimize the designs. Even with the growth of Parametric Solid Modeling and analysis software that do most of the computations for the engineer, mathematical understanding is required to use these tools robustly and adaptively. See Appendix B for the role of mathematics described in the ITEA Standards for Technological Literacy.

Mathematics as an Enabler of Learning Qualitative Concepts

In addition to M being a core part of S, T, and E, it is also an enabler of qualitative concepts, by virtue of being a thinking tool. A much longer paper is required to flesh this idea out properly.

Here I can only provide a few interesting examples.

At the macro level, some counter-intuitive results by Sadler and Tai (2007) speak to this function of mathematics. They conducted an analysis of what predicts performance in college science classes, focusing on the amount of high school science courses students had had, statistically adjusting for a myriad of variables that might be confounds in those relationships. They were interested in whether having prior physics courses helped students learn chemistry and whether having prior chemistry courses helped students learn biology (in order to argue for reordering high school science courses). Although that is not our focus here, it is interesting that there was in fact no clear transfer benefit across sciences, which at least shows us that logical support relationships don't always turn into learning benefits. Most relevant to us is the predictive role of high school math courses: The more high school math a student had, the better the student did in their science courses. In fact, prior math was as beneficial as prior coursework in the exact science being studied (e.g., prior physics to current physics course). Especially interesting is that the magnitude of this prior-math effect was equally strong for college courses in physics, chemistry, AND biology. While one could understand why it would be critically useful to physics and chemistry from a simple content analysis, that it was just as helpful to learning college biology is a little counter-intuitive because there is a lot less mathematics in introductory college biology than in physics and chemistry. Somehow this mathematics background is serving as a conceptual resource for students in their biology classes.

Let us move to the other end of the instructional spectrum. One of the early goals of math instruction is teaching number sense and the number line. At the early elementary level, being able to say that 5 sits near the middle of a line going from 1 to 10 (and later that 50 sits in the middle of a line going from 1 to 100) is one of the best current predictors of later math learning. Having that number sense enables the problem solver to estimate answers and check their own problem solving as they go, which is just as useful for science and design as it is for math problem solving. Moreover, mathematics quickly comes to involve thinking about numbers whose magnitude we would not naturally understand. 1,000,000 or even 1,000 are not numbers we can really grasp intuitively except by appeal to mathematics-created thinking tools (e.g., their base-ten structure). Many aspects of science and engineering involve work at non-human spatial and temporal scales. Physics and chemistry often involve phenomena that happen incredibly quickly on objects of unthinkably small sizes. Even in biology, the complex processes of a cell are happening inside something smaller than the dot on this 'i'. Astronomy and geology involve processes at the other end of spatial and temporal scales. The orders of magnitude are important to understanding how the phenomena occur, and a basic mathematical understanding of scale serves as the conceptual foundation for understanding these orders of magnitude, thereby supporting the learning of science concepts that are not overtly equation-based (e.g., plate tectonics).

Continuing along this thinking tools path, Rich Lehrer and Leona Schauble have obtained startling strong outcomes with early elementary school in science by a thoughtful integration of mathematics as a thinking and problem-solving tool. In the classrooms they have helped design, students work with the teacher to develop mathematical abstractions (e.g., variations on USA Today-like graphs which eventually transition to more abstract graphs and tables) to help them answer scientific questions. Thinking mathematically helps them refine their scientific questions, for example, making clear the distinction between the length, width, and area of a plant leaf, or the distinction between absolute growth and percent growth. The conversations found in these elementary classrooms are more typical of advanced undergraduate or graduate science classrooms, and that was only achieved by building up mathematics as a thinking tool.
Related results have also been found in the teaching of engineering design, particularly in helping to reduce the complexity of the systems that are being designed. For example, Lehrer and Schauble (1998) found that fifth graders could use mathematics to reduce the conceptual complexity of gear systems, and thereby develop a better understanding of they worked. Similarly, when fifth graders were encouraged to use math in predicting behaviors of a balance

scale, Schwartz, Martin, and Pfaffman (2005) found that children moved from considering only one variable to having an adult-like integrated two-variable understanding. In general, contextualized mathematics provides an abstraction layer that helps students focus on the critical elements of the situation (Noss, Healy, and Hoyles, 1997).

Solutions to Re-Integrating M into K-12 S, T, and E

There are number of large barriers to the integration of mathematics into S, T, and E: 1) the weak and uneven level of math knowledge of students; 2) the lack of experience or interest in math instruction by teachers of S, T, and E; 3) the lack of time in the curriculum (especially in science) to also teach mathematics; 4) the relative hodge-podge placement of particular S, T, and E topics at different grade levels in different schools, making textbook design that builds on prior knowledge even more difficult; and 5) differences between how math is done in math classes and how math is done in S, T, and E classes. Rather than discuss these challenges to integration at length, I will suggest three simple solutions, which I phrase as design principles for S, T, and E curricula design.

1) *Recognize and build upon disciplinary differences in the use of mathematics*. Sometimes differences exist between how a mathematics task would be done in the mathematics class and how students are being ask to do that task in the S, T, or E class. For example, in the mathematics class, students are frequently asked to generate multiple representations of a situation (e.g., a graph and a table) and explain the relationship between those representations. In the science classroom, it would be unusual to do both. As another example, there can be notational variations (e.g., different ways of marking angles or indicating derivatives). Teachers of S, T, and E should find out from math teachers in their schools what conventions are being taught, and explicitly explain the differences/similarities to the students. Explicit comparison across variations is a generally powerful teaching strategy for building deeper conceptual understandings less tied to irrelevant situation-specific details.

2) *Identify and reinforce/use existing mathematics*. In every classroom, students come in with some mathematics knowledge. Teachers of S, T, and E should identify what that knowledge is, via pretests and via consulting with math teachers in their school. They should then find ways of including science and design activities that make explicit use of that mathematics knowledge. Designers of science, technology, and engineering curricula sometimes have extension activities that use mathematics, which teachers should make more use of when the mathematics content is appropriate. The curriculum designers should include more such extension activities, covering a broader range of mathematics. If students already have this mathematics knowledge, why is it important to reinforce this knowledge? First, it is unlikely that all of the students have such a solid grasp of the mathematics that they would not benefit from additional practice. We now know that practicing a given skill or concept over a wider range of time is extremely helpful for maintaining that skill or concept. We also know that practice across contexts is very helpful for improving transfer to new situations. Second, using mathematics as part of the instruction will give students a deeper understanding of the conceptual material. In other words, practice and use will both serve as a thinking tool in the current classroom as well as insure that it will still be around as a thinking tool in later classrooms.

3) *Foreground and teach* *<u>one</u>* *piece of new mathematics in a given month*. Science, technology, and engineering often depend upon a very broad range of mathematics (e.g., matrix algebra, calculus, and geometry). Sometimes, the students in the S, T, or E classroom need mathematics that will not normally be covered in their mathematics classroom for another year or more (or they did not quite understand it when it was covered previously). If the mathematical concept is particularly important as a thinking tool for the topic at hand, it is necessary to include significant instruction on this mathematics concept in the S, T, or E classroom.

However, because teaching (and learning) a new bit of mathematics is not a trivial chore, it is likely a bad idea to attempt to teach many pieces of mathematics in one S, T, or E course. I suggest that it would be better for both teacher and students if a more focused approach were taken. On the teacher side, there is less pedagogical content knowledge (i.e., how to best teach a particular idea) that needs to be acquired if the range of math concepts to be taught is tightly bounded. On the student side, the concept is more likely to be learned and then useful as a thinking tool if one math concept is examined in depth rather than many math concepts examined superficially.

Focusing on particular math concepts in the context of a S, T, or E classroom is not a trivial chore, and likely is a chore that must be done at the curriculum designer level rather than at the teacher level. First, it involves adjusting the choice of activities and situations so that a given mathematical concept shows up repeatedly AND other mathematical concepts can be ignored. For example, if you try to teach some aspect of algebra in a robotics curriculum, you probably want to remove the need for statistics concepts during that instruction (which might involve using canned very clean data rather than real data).

Second, it requires orchestrating a sequence of activities and situations that go from relatively simple, foundational instantiations of that mathematical concept to increasingly more complex, sophisticated instantiations of that mathematical concept. For example, a robotics activity might start with building the basic idea of a proportional relationship between two quantities, and then later activities might help students attend to the proportionality constants involved in that relationship. Similarly, early activities might start with directly proportional relationships, whereas later activities might transition to inversely proportional relationships.

Conclusion

We are currently in need of substantial change in how mathematics is integrated into science, technology, and engineering instruction. The solutions that I have presented are relatively simple ones and perhaps overly simple. Yet, if implemented widely, they may be powerful enough to produce substantially different learning outcomes for the whole STEM spectrum. Considerable research is required to understand whether these solutions will indeed cumulate to substantially different outcomes, and also to determine effective methods for widely implementing these solutions.

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Appendix A: Mathematics in the National Science Education Standards

The standards for teaching note that teachers should

"Be able to make conceptual connections within and across science disciplines, as well as to mathematics…" (p. 59).

Regarding science content, mathematics is mentioned many times, although never inside the standard for a particular piece of science, and so this element could be missed:

"Prediction is the use of knowledge to identify and explain observations, or changes, in advance. The use of mathematics, especially probability, allows for greater or lesser certainty of predictions." (p. 116-117)

"Mathematics is essential for accurately measuring change." (p. 118)

"The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design." (p. 145)

"USE MATHEMATICS IN ALL ASPECTS OF SCIENTIFIC INQUIRY. Mathematics is essential to asking and answering questions about the natural world. Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations." (p. 148)

"Mathematics is important in all aspects of scientific inquiry." (p. 148)

"Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results." (p. 148)

"Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical." (p. 148)

Appendix B: Mathematics in the Standards for Technological Literacy.
"Students should have opportunities to use simulation or mathematical modeling, both of which are critical to the success of developing an optimal design." (p. 41)
9-12 standards: "W. Systems thinking applies logic and creativity with appropriate compromises in complex real-life problems. It uses simulation and mathematical modeling to identify conflicting considerations before the entire system is developed." (p. 42)
9-12 standards: "BB. Optimization is an ongoing process or methodology of designing or making a product and is dependent upon criteria and constraints. Optimization is used for a specific design purpose to enhance or make small gains in desirable characteristics. An optimum design is most possible when a mathematical model can be developed so that variations may be tested." (p. 42)
"J. Technological progress promotes the advancement of science and mathematics. Likewise, progress in science and mathematics leads to advances in technology." (p. 52)
"J. Make two-dimensional and three-dimensional representations of the designed solution. … A model can take many forms, including graphic, mathematical, and physical." (p. 121)
"P. Evaluate the design solution using conceptual, physical, and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed." (p. 124)
Connections to other disciplines:
K-2 standards: "A. The study of technology uses many of the same ideas and skills as other subjects. For example, many ideas learned in mathematics are also used in the study of technology, such as the basic rules of numbers and using numbers to represent measurements" (p. 46)
3-5 standards: "They could apply their estimation skills learned in a prior mathematics lesson to determine who far their rockets could fly." (p. 48)
6-8 standards: "Scientific and mathematical knowledge and principles influence the design, production, and operation of technological systems. … Mathematical concepts, such as the use of measurement, symbols, estimation, accuracy, and the idea of scaling and proportion are key to developing a product or design and being able to communicate design dimensions and proper function." (p. 50)
In vignettes:
"The students also put their mathematics skills to work to determine if the cubic feet per minute (CFM) rating of the fan was sufficient for the job. After completing the calculations, they decided that the fan did evacuate the fumes quickly enough to avoid inhalation." (p. 29)

Moving Technological Literacy Forward Within the STEM Paradigm

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> **"Daring ideas are like chessmen moved forward; they may be beaten, but they may start a winning game."**
> KAUFFMAN Thoughtbook 2007

The Game

Not all educators are innovators, nor are they necessarily daring with their ideas. However, progressive educators do attempt to move forward and make adjustments as they practice the art and science of teaching. The thinkers and leaders of every field of education constantly go through the exercise of trying to deliver more rigor through teaching and learning. This is a normal, healthy exercise resulting in different and sometimes new avenues of thought. New research is put in place or a different curriculum project is attempted. Such is the case for those who are currently interested in education pertaining to the delivery of technological literacy or increasing one's technological capability.

Outside forces or dynamics can be a factor in this kind of thinking, especially when the topic deals with technology. Philosophical perspectives are challenged; for such exercises require change and the reexamination of opinions as a result of discussions and research evidence. The dynamic nature of the study of technology alone creates the need for constant adjustments as to what students should know and be able to do to be technologically literate in order to be a productive member of society.

The fields of technology and engineering education are undergoing these phases of thought in earnest at this point in history. The reasons are numerous. The lineage, differences, commonalities, baggage, and attributes of these two subjects can be outlined by most involved educators or engineers. A variety of arguments are given that include as many definitions and perspectives as there are people. One's formal background, whether evolving from education, engineering, vocation or career training, or a corporate perspective, becomes a factor in directions attempted or taken. Finally, politics and capitalism evolve as groups attempt to profit from the enterprise known as technology and engineering education. Education is one of the biggest enterprises in the United States—a fact often overlooked in philosophical discussions. The term, "follow the money," has just as much meaning for this discussion as any in education.

It is a commonly accepted fact that scholars or stakeholders from the various disciplines think differently, approach a problem or opportunity differently, and create their own guidelines or standards. These differences enable us, as educators, to help our students look at things through different lenses: in a sense, to offer them insights into different ways of knowing. (Scientists know about the world through inquiry, mathematicians through analytical reasoning, engineers and technologists through designing and constructing.) This thinking becomes their culture and further defines their field of study. Technological literacy crosses many fields or disciplines because of its integrative nature. At the same time, a form of academic snobbery evolves as the stakeholders in each discipline charge forward with their reasoning for the importance of their point of view or discipline. Such is the case for technology and engineering educators who each have a common purpose leading toward technological literacy.

Researchers, practioners, academics, and scholars from technology and engineering education overlap in thought and practice, even though they are often located in different colleges within universities, aim for different outcomes for their students, and provide a contribution to society through their respective actions that further their professions. The fields of science and mathematics experience these differences and commonalities when education about and practice of the discipline in society are considered.

At the same time, education in the U.S. is going through a period during which standards, assessments, and more rigor are considered paramount. Reading, mathematics, and science are a valued part of education. Educational practice involving science, technology, engineering, and mathematics (STEM) are subjects with commonalities within the school curriculum. Funding, from local to national levels, is shaping the future of these areas of study as both a STEM unit and as separate subjects. One anticipated result is a more educated population prepared to take on careers that will advance our society and nation as a result of being technological and scientifically literate with accompanying capabilities.

The following discussion is intended to progress thought and practice relating to technology and engineering as a part of the larger STEM educational thrust. Reflective questions are provided in an attempt to expand exploration of these issues, work completed, and possible directions that research and practice may take. The purpose of this paper is to offer evolutionary ways to think about technology and engineering, what is important about teaching technological literacy, and how such teaching and learning may be delivered. Perhaps thought and discussion will create ideas that move education forward like chessmen—initiating a game that can result in making students the real winners.

Changing the Way We Think About Technology and Engineering

Writers and thinkers like Daniel Pink (2006) describe the last few decades as belonging to a "certain kind of person with a certain kind of mind." The type of person who has been thought to have excelled is the computer programmer who can create code, the MBA who can crunch numbers, or other such occupations known for a type of thinking thought to involve numbers or mathematics that far exceed the average person's knowledge or capability. These thoughts have been furthered by No Child Left Behind (NCLB) legislation, state initiatives that place emphasis on more rigor in selected subjects and types of thinking, scoring higher on selected tests, and determining one's ability to succeed through types of assessments thought to produce innovation and a stronger, brighter member of society. Unfortunately, this thinking has not attracted more students to the STEM subject fields as is evidenced by the shortage of people who desire to spend their lives in occupations requiring this type of thinking. The attraction is simply not there when it comes to enticing our societal members to know more mathematics and science when approached in this manner.

The future very possibly belongs to a different type of thinker, who at this point is not receiving attention because his or her mind works differently as a creator, pattern recognizer, and determiner of meaning. Pink identifies these thinkers as artists, inventors, designers, storytellers, caregivers, consolers, and big-picture thinkers. Could we be moving from an economy of logical, linear, computer-like capabilities to one built upon inventive, empathic big-picture capabilities? We already know that minimal computer thinking tasks and engineering work are being farmed out to other countries with a cheaper labor force and that the more sophisticated computer programs can themselves develop programs that can be used in more and more situations.

We continue to recognize, if not idolize, individuals who were leaders in the dominant thinking paradigm of the last few decades. People such as Bill Gates, Paul Allen, Steve Ballmer, Steve Jobs, Eric Schmidt, and Bill Joy guided us through the age of this type of thinker (Gladwell, 2008). While we should be grateful for their leadership, they are examples of a way of thinking that was comfortable to them because they each spent literally 10,000 hours perfecting techniques and thinking during a point in history when it was most valued. The result has been a material abundance for them and many others. Why? Because their minds work that way. Is this the only way that people want to make change, chart their future, and build a society that is tied to one type of thinking?

Respected thinkers, such as the Dalai Lama, indicate that the very purpose of life is to seek happiness. Our natural inclination is toward happiness, giving meaning to what we do, and pursuing work that promotes ideas or concepts that are of personal interest. These ways of thinking need to be placed into a context that causes us to want to learn more about many different things. We should infuse learning with joy through contexts that motivate us to learn logic and reasoning used in mathematics, about the natural world as learned in science, and design used as we create and express our knowledge. Being mathematically, scientifically, or technologically literate can be the result of seeking happiness while learning about ourselves and our society. The typical learner will not achieve and study more science, technology, engineering, or mathematics because it is valued by a certain type of thinker. What is being measured and treasured through assessments is valued by the test givers, but not necessarily the prospective learner. When one seeks happiness in learning, the need to achieve will naturally cause more rigorous learning. STEM educators would do well to keep these ideas in mind as they move forward with research in teaching and learning. Without meaning and happiness in a proper context, very little desire to learn will result. Our job is more than leading the student to the water of knowledge for a drink. It is to make the student thirsty in the first place. When the student is thirsty, the "need to achieve" will have arrived and learning will progress.

Questions to ponder:

- Why do learners in certain countries have a stronger desire to achieve in STEM subjects than in other countries?

- What is the correlation of one's "need to achieve" in STEM subjects as it relates to self interest and learning styles?
- What kind of person and type of mind will be valued by next-generation societies and how will they relate to STEM subjects?

What is Important When Teaching About Technological Literacy?

To learn more about the importance of teaching technological literacy, we first need to be aware of what students are thinking about their education. Only 30 percent of high school seniors rated their schoolwork as meaningful in 2006 compared to 37 percent ten years earlier (Bachman, Johnson, O'Malley, 2006) It is distressing that as students progress through school levels, their interests and attitudes toward STEM subjects become more negative (Morell & Lederman, 1998). These research findings should be of concern to STEM educators and influences technological literacy research and practice.

Research during the last 15 years has resulted in a number of significant studies pertaining to technology, innovation, design, and engineering at the K-16 levels of education. This research resulted in a rationale and structure for the study of technology (ITEA, 1996, 2006), standards for technological literacy (ITEA, 2000/2002/2007), standards for programs, professional development, and assessment (ITEA, 2003), addenda for those standards, curricula, approaches to assessing technological literacy (ITEA, 2004) (ITEA, 2005) (ITEA, 2005) (ITEA, 2005), a technological literacy assessment framework probe launched by the National Assessment of Education Progress, state and national STEM legislation, as well as a continuous stream of articles and research projects pertaining to and development of STEM curriculum. The National Academy of Engineering (NAE) has been very active with research pertaining to why all Americans need to know more about technology (NAE, 2002) and approaches to assessing technological literacy (NAE, 2006). All of these research studies have served as a basis for much of the technological literacy taught in schools today. Agencies and associations that have made major contributions towards this evolving work have included the National Aeronautics and Space Administration, National Science Foundation, National Academy of Engineering, National Research Council of The Academies, International Technology Education Association, and the American Association for the Advancement of Science (1996).

Unlike mathematics and science education, the research and progress pertaining to technology and engineering has less longevity due to its more recent appearance in the school curriculum and its designation as an elective subject. Shakrani and Pearson (2008), in their issue paper for the National Assessment Governing Board, noted that, "Presently, little is known about the level of technological literacy among our students." The authors further note that the starting point for improving technological literacy must be to determine the current level of knowledge, understanding, and capabilities of our students.

The National Science Foundation has been a STEM education research leader by providing direction and funding to address the levels of rigor and learning progression pertaining to technology and engineering education. Many aspects of technology and engineering education have been addressed as a result of its support. However, this body of completed research is still small in scale and is only the beginning of many years of new findings that will help educators (www.nsf.gov/).

This leadership in philosophy and funding has not necessarily resulted in a more cohesive relationship between technology and engineering educators. A considerable amount of time has been spent elaborating on the differences between the two areas. Perceptions relating to career expectations, definitions, amount of rigor, and research findings are used to further each stakeholder's point of view. However, there is one common value that is accepted by almost all concerned, regardless of the discussion—the need to increase rigor and knowledge learned about technological literacy. What does it take to accomplish this outcome? What research is important? How much rigor is adequate? How much knowledge is enough? What teaching and learning will produce a more positive result? These are all questions that become a part of life's work as the fields of technology and engineering education increase in importance as a part of the essential education for *all* students.

The discussion about technological literacy cannot go very far without addressing the nature and role of technological or engineering design. Design is as important to the technological and engineering world as inquiry is to the scientific world. How design is taught certainly affects the level of technological literacy learned. An extreme example of such teaching would be the educator who approaches design as a form of gadgetering with no real known outcome other than that the students enjoyed the hands-on experience (Hacker & Burghardt, 2008). This example contrasts with experiencing informed design aimed at applying mathematics, science, technology, and more in a learning activity containing as much learning gratification as the gadgetering example. The second example is STEM-standards based (rather than a random activity that may be standards-related), with an intended learning outcome that could be assessed. The importance of design in learning more about technological literacy cannot be underestimated. We have only begun to understand what we can do with design through research conducted to date. Teachers need to know more about what is appropriate and good design using informed student experiences.

Standards for Technological Literacy (ITEA, 2000/2002/2007) produced a large body of content not previously identified. A significant "next step" would be to identify common focal points for each grade level, thereby creating a more coherent technological literacy curriculum. This would allow teachers to commit more time each year to identified topics that have some coherency through all grade levels. The National Council of Teachers of Mathematics (NCTM, 2006) has already completed such a research process. It is incumbent upon science and technological literacy educators to follow with similar research as soon as it is feasible.

These research ideas are in their infancy and will need to be nurtured as study and work progress. The end result will be a stronger STEM education that brings enjoyment to learning principles, techniques, and processes pertaining to the technological nature of our society and its importance to mathematics and science.

Questions to ponder:

- What is the appropriate STEM level of rigor for the grades- K-2, 3-5, 6-8, and 9-12?

- What research needs to be addressed pertaining to the integrative nature of each STEM subject?

- What are the most appropriate and effective ways to structure teaching and learning about design?

- What are the common focal points at each grade level for teaching about technological literacy?

What is Our Daring Idea and How Will We Know When We Have Won the Game?

What we are ultimately seeking in our discussion about technology and engineering education and with STEM as an educational initiative? We may be looking for research informed by practice and practice informed by practice. We seem to be looking for a systematic way of advancing research and practice as we work toward making serious gains in learning. We lack a sound research agenda aimed at providing direction for future work and with an eye toward progressing technological literacy and STEM learning. The big idea may be simply stated: What do we want our kids to know and be able to do about technological literacy and how do we teach in a way that will help students be effective learners? The route to accomplish the idea gets very complicated.

Our attention is directed toward the professional development of the teacher and higher education institutions that might be preparing STEM teachers. The ideal teacher would have a background in each of the four STEM areas—admittedly a rarity. Therefore, we must build models of integrative STEM programs that will prepare the best teacher that the institution is capable of producing. Without reform models, teacher preparation institutions are very likely to produce teachers prepared in a vacuum or silo, where each subject is taught separately with very little integration. This will take considerable effort by institutions that currently prepare teachers of mathematics or science—for the content areas of technology and engineering may be left on the sidelines. Higher education models in which both colleges of education and engineering exist need to explore the interaction between the colleges for the good of K-12 education. Depending upon the institution, technical courses could help provide the type of integrative interaction that is sought between education and engineering courses.

As we address the integrative nature of STEM subjects, we must also address the integrative nature of the domains of learning. For example, we’ve only begun research to gauge the amount of learning that can take place in the various domains as a result of teaching about technological and engineering design. How do science and technology support mathematics learning? Do design and inquiry have differences, but on a day-to-day basis look the same? What is the role of failure in learning, as can happen in engineering design? Can we do a better job of creating affective domain learning through the teaching of technological literacy? What effect does virtual learning have on understandings related to technological and engineering processes? A large research agenda lies ahead pertaining to the domains of learning within integrative STEM education.

Finally, we must address the incentive for teachers and students to want to be a part of a STEM education. It is already acknowledged that students do not gain a “need to achieve” due solely to assessments. A greater purpose must exist that relates to the needs and interests of the students. Considerable research has now been completed pertaining to why people are attracted to various occupations. We must explore those research findings and take advantage of the reasons that students might want to be a part of a STEM education.

For example, a student is more likely to enter the engineering profession today to protect or improve the environment rather than building computer programs. The purpose, most often, is much larger than the technical expertise that is often promoted or the threat of how challenging a profession is to enter. The STEM professions must be promoted as a way to improve our society, rather than promoting them as highly skilled, difficult occupations for the geeks of the world. Interest and meaning toward making a difference and rising to the challenge of using technology in solving environmental, energy, and housing problems is often enough to attract student interest. We must become better at promoting the societal benefits and the boundless opportunities of a STEM education. The result will be students curious and eager to learn about technological literacy and how to use STEM subjects to change the world for the good of humanity.

Questions to Ponder:

- What should be the major components of a research agenda to advance teaching and learning for integrative STEM education?
- What are effective models for STEM professional development experiences?
- What models for integrative STEM higher education programs are effective for liberal arts, teacher preparation, and major research institutions?
- What research strategies should be employed to gain important knowledge about learning domains within integrative STEM education?
- What incentives work for encouraging students into STEM studies?
- How can we, as educators, change our teaching styles and environments to better match the learning styles of our students that are so defined by interactive learning : games simulations, and social networking?

The Game Winner

This paper began with a quote pertaining to daring ideas and starting a winning game. The challenge to prove the worth of technological literacy as an important part of essential education in our society may just be the start. We may well be at the beginning of a new winning game whose time has come for the next generation of learners.

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Results From Work with Middle School (Grades 6-7) Mathematics and Science Teachers: Possible Directions for Study

Gay Stewart, representing *KIDS*

Research indicates that students begin to lose interest in mathematics and science around their middle school years (Ayers & Price, 1975; Finson & Enochs, 1987; Simpson & Oliver, 1985). National academies, government agencies, academic institutions and the private sector all share a growing realization that innovation is the key to global competitiveness, economic strength and national security. These groups also agree that innovation leadership depends on the ability of America's schools to produce the next generation of innovative scientists and engineers. The University of Arkansas NSF GK-12 program is working to meet this goal through a program called "K-12, I Do Science" or KIDS.

At first, our focus was primarily upon science, the PIs' area of expertise, but broadened to mathematics for two primary reasons. First, it is much easier to develop certain concepts in science and scientific reasoning in parallel with mathematics. Second, mathematics is a subject included on state benchmarks, and therefore much easier for which to assess learning gains. Although the model used may be different than those in use by other institutions, some of the potential research questions arising from the implementation in math, science, or math and science classrooms together, could be of significant interest in any project involving middle school mathematics.

The *KIDS* program is based on a "learning by doing" approach in the middle school setting. University graduate student fellows in math, science and engineering are trained to work in partnership with middle school faculty. Together they guide students through hands-on experiments and projects. The middle school students learn mathematics and science by posing their own scientific questions and working to find the answers for themselves. The *KIDS* program attempts to increase student interest in science, math, and technology by placing scientists (graduate students) directly in middle school classrooms on a weekly basis. The program was essentially composed of graduate students in science and mathematics fields and middle school faculty who collaborated to create lesson plans and activities to teach key scientific and mathematics content and facilitate student interest and desire to learn.

Although the research results presented are based on the classrooms where graduate students were involved, we also had pre-service mathematics and science K-12 faculty who participated in the summer workshops before going out into their own classrooms. These participants have anecdotally reported successes in student learning. A significant research question is “Can we replicate these gains in classrooms without graduate student involvement?” For these new faculty, there is no “before treatment”, so we would need to do a very careful job of constructing a matched classroom situation to compare results, matched for students as well as teacher preparation.

As accountability in mathematics and science has become essential in middle school education, a variety of instructional techniques for teaching have been investigated. Inquiry-based learning, our chosen emphasis, has gained acceptance as a method for creating interest among students as well as for promoting the benefits of science and mathematics knowledge and skills (NRC, 1996; Chang & Mao, 1999; Gibson & Chase, 2002; St. Omer, 2002). The 1999 TIMMS Science Benchmarking study (Martin, et al., 2001) indicated that engagement in scientific experimentation and the use of investigative methods in the classroom had a positive impact on science achievement.

Our premise is that students who explore their own curiosity, reach for their own ideas, and engage in their own experiments are experiencing inquiry and innovation and are learning science. Specifically, we attempt to give middle school faculty the tools for the integrated teaching of mathematics, science and technology in the context of everyday life. Our middle school faculty worked on aligning mathematics and science curriculum with state standards and assessments, and determined which mathematical concepts connect to specific portions of the science and technology standards. They worked with graduate students in the sciences to develop lessons where these concepts could be taught.

During the academic year, the program provides experiences for administrators and parents. Knowing that some parents will have difficulty in supporting their children's interest and development of science, mathematics and technology skills, we hold a "parent hour" one night each month. During this time the graduate fellow and middle school teachers discuss the science and mathematics skills that the children are learning, so that parents can choose to make an even greater difference. Parents engage in some sample activities with their children. Administrators also participate in a learning experience similar to the students', but with a narration of the elements that make the inquiry-based lesson valuable to the school and how the national and state teaching standards are addressed by the *KIDS* program. A "mall day" is held each spring, serving as an outreach to not just the parents, but the entire community.

The first iteration of the program involved too much teacher time in the summer, almost a full month. Working closely with the teachers, and carefully considering their needs and interests, the following schedule has evolved and been consistently used for the last several years (Four weeks, Monday-Friday):

- An afternoon opening orientation with the fellows, the Friday before the last week of school.

- Monday-Thursday week 2, fellows work with College of Education faculty on issues such as standards, what a middle level classroom and its students are like, and general teaching practices. The fellows come to appreciate the teachers as experts on student learning and classroom management.

- Friday: an intense one-day workshop on inquiry. Teachers arrive in the afternoon.

- One-day symposium on current concepts in science for teachers and fellows.

- Two-day team-building "camp" including an overnight stay. Teachers and fellows work together in various pairing and groupings. At the end, each teacher pair and each fellow is asked to make a list of their top three choices for a match for the academic year. This information, combined with observations made during the camp, is used to make these matches, which are then tested during the next few meetings.

- Thursday morning all participate in a high-quality inquiry-based activity. In the afternoon follow up and group discussion help highlight what made the activity so effective, and what we should be striving for in the materials and activities we will produce over the remainder of the program.

- Friday morning, previous fellows are chosen to present their exemplar lessons. In the afternoon, the Center for Math and Science Education, a resource for teachers, is explored.

- During the third week, G. Stewart teaches a workshop on lab and classroom practices. The 10 teacher-fellow groups work together. There is continued development of the theme of experts in various fields working together to make something special (teachers have spent years developing knowledge of students and teaching, fellows have intensely studied science and mathematics). The days are divided into morning and afternoon sessions. The first three sessions involve more exemplar activities and discussion, working through a learning cycle. Monday afternoon toward the end, groups are asked to begin thinking what their first trial activity will be. The Tuesday afternoon session, these ideas are formally proposed, and necessary resources identified. The remainder of the week is a mixture of activities on topics requested by the teachers, and development of these trial activities, including lesson plans that frame them, and tie them to the state standards.

- During the fourth week, a "class" of volunteer middle school students attends each morning. Two of the groups will practice their trial activities on this class each day. The afternoons are spent debriefing the activities, and helping the fellows develop a "presence" that works with this age group.

- For the remainder of the summer, the fellows and teachers work flexibly with each other to develop the activities they have agreed on for the start of the coming year. These are submitted and reviewed and become resources for all participants.

None of the data presented represent true complete research projects, but indicate areas of interest or items for further study in any project with similar goals. The evaluation team has produced many interesting results on the KIDS project. These data led to some of those explorations.

Changes in the first few years.

Sixteen K-12 faculty participated in the *KIDS* program, representing ~27% of the mathematics and science K-12 faculty in seven schools. Over 36% of the mathematics and science K-12 faculty from these schools applied for the program, representing a 75% inclusion rate. Ninety-two percent of the *KIDS* K-12 faculty have been female and all have been Caucasian. Highlights of longitudinal impacts that K-12 faculty are changing their instructional methods used in the classroom include a:

- 28% increase in time using inquiry learning activities (49 minutes per week per class);
- 34% decrease in traditional lecture and textbook activities (26 minutes);
- 54% increase in the use of manipulatives and active learning tools (48 minutes);
- 60% increase in technology usage (14 minutes per week per class); and
- 71% had high confidence levels creating inquiry activities with only 14% before *KIDS*.

It is important to point out that the concept of inquiry is carefully developed. The difference in "hands-on" and "minds-on" activities is not always made clear. A December 19 (year unknown) article by Arpi Sarafian in the LA Times "Is Hands-On Learning Sending the Wrong Message?" and the supporting letters it drew from long-time practicing elementary teachers suggesting that the "playground has been moved into the classroom" and repeated support in California for "direct instruction" clearly point out the danger inherent in this confusion. Even a highly interactive activity does not ensure that the students will make the mental commitment necessary for significant concept development to occur. When this happens, parents and teachers will assume it is the method that is not effective, if they do not realize what was missing.

These changes have had an impact.

Over 2,000 students in seven schools (approximately 31%) are estimated to have been in *KIDS* classrooms, including about 30% in minority ethnic groups. Highlights of longitudinal outcome measures for K-12 students include the following outcomes.

- Our evaluation team tracked 933 students in middle schools from 4th to 6th grade on their standardized test scores. The control group of 498 saw a 10% decrease in scores between 4th and 6th grade, consistent with the Arkansas and national trend (National Center for Education Statistics, 2000) from 4th through 12th grade. Meanwhile, however, the 435 GK-12 students had a 10% increase.

- In one of our schools, the GK-12 mathematics class (with randomly selected students within a school of 400 students) had 6 of the school's top 10 mathematics students and 43% of the class tested "advanced" compared to the school average of 20% on the standardized test.

- Students in *KIDS* Science classrooms were twice as likely to find a career in Chemistry, Physics or *<u>Science Teaching</u>* as "Very Interesting" as compared to the control group.

- Students in *KIDS* Mathematics classrooms were twice as likely to find a career in Biology, Physics or Computers as "Very Interesting" as compared to the control group.

Increasing student performance in an area of study is aided by first developing an increased interest in the subject and an understanding of the usefulness of the subject by the students. In

1995, Schiefele and Csikszentmihalyi investigated the relationships among interest in mathematics and many other factors. They found that quality of experience with the subject matter was mainly related to interest. Researchers have also evaluated students' attitudes toward science. Morrell and Lederman (1998) found that fifth grade students had more positive attitudes toward science than both seventh and tenth grade students. On average, the fifth grade students' scores were still only in the "undecided" range. Many of the students in their study who did have positive attitudes indicated their families had encouraged their interest in the subject.

Despite increases in mathematical performance, as judged by state benchmark exams, science-only participation appeared to have a positive impact on science confidence and interest scales and a negative impact on mathematics confidence and interest scales, even though the general relationship between the mathematics and science confidence and interest scales were positive. Math-only participation appeared to have a positive impact on both mathematics and science confidence and interest scales. All but one of the graduate students that participated in the early years of the project had been in the fields of science and engineering, thus the majority of the inquiry-based activities conducted in the classrooms were science-based. The educational activities in the science classrooms typically consist of science-based content and the application to math-related skills may not have been obvious to the middle school students in these classes. Thus, having a science or engineering graduate student only in a science class may actually result in students' having a lower perception of confidence and interest in math. It may be that the increased interest in conducting inquiry-based science activities, without incorporating inquiry-based activities into the mathematics curriculum, results in this lower perception of math. The graduate students in the mathematics classrooms were also from science and engineering fields and commonly use science-based educational content to create mathematics educational activities. However, it is likely that the connections were much more explicitly made.

A few examples of results of various combinations of instructional emphases from early in the project are presented (before teachers were sharing fellows between mathematics and science), to possibly open some discussion on important parameters involved in the improvement of mathematics learning by integration of mathematics and science education. Hurley (2001) defined several types of integration. The two that are most closely parallel to these efforts are "partial" and "enhanced". Partial integration is found where science and mathematics are taught partially together and partially as separate disciplines in the same classes. This happened when the mathematics and science teachers were working together. Enhanced integration happens when either science or mathematics is the major discipline of instruction, with the other discipline apparent throughout the instruction. This would be the most appropriate model for when the mathematics or science teacher was working alone with a fellow. Changes reported are the shifts in benchmark scores from 4th to 6th grade. Treatment group is 6th grade. Two sets of statistics are given, before treatment, and the second year, where the teachers had participated for two summers and offered their second year of modified instruction. The weakness in these data is that the teachers in both the GK-12 treatment groups and the control groups had a range of experience and preparation level, and nothing was done to try to unpack this to see if it had its own effects.

- All participating schools
    - Mathematics teachers working on their own to increase inquiry

        - Before treatment: Δ=0.03 (control group Δ= 0.15)
        - After year 2: Δ=0.09 (control group Δ= 0.03)

    - Science teachers working on their own to increase inquiry
        - Before treatment: Δ=0.21 (control group Δ= 0.15)
        - After year 2: Δ=0.15 (control group Δ= 0.03; a larger effect despite size)

    - Science and mathematics teachers working together to increase inquiry
        - Before treatment: Δ=0.30 (control group Δ= 0.15)
        - After year 2: Δ=0.24 (control group Δ= 0.03; a larger effect despite size)

- Community of approximately 50,000, with a high minority, ESL population
    - Mathematics teachers working on their own to increase inquiry
        - Before treatment: Δ=0.17 (control group Δ= 0.13)
        - After year 2: Δ=0.19 (control group Δ= -0.01)

    - Science and mathematics teachers working together to increase inquiry
        - Before treatment: Δ=0.30 (control group Δ= 0.13)
        - After year 2: Δ=0.24 (control group Δ=- 0.01; a larger effect despite size)

Another item of interest was to see if the GK-12 program had differential impact on students based on their initial ability levels. The students were placed into three groups, those below -0.33 standard deviations below the mean in 4th grade, those from -0.33 to +0.33 standard deviations from the mean, and those over 0.33 standard deviations above the mean. The changes here are reported for "z-scores" of the benchmark mathematics exams between 4th and 6th grades. The data suggest that the positive impact was on catching the lower-performing students up, but not in serving the average-performing students. It is hoped that later modifications as the teachers' confidence in inquiry and deeper coverage of the content increases and is reflected in extensions to the activities, that the average-performing students could also significantly improve.

- Low:
    - Mathematics teachers working on their own to increase inquiry
        - Before treatment: Δ=0.33 (control group Δ= 0.41)
        - After treatment: Δ=0.17 (control group Δ= 0.34, a decrease)

    - Science teachers working on their own to increase inquiry
        - Before treatment: Δ=0.33 (control group Δ= 0.41)
        - After treatment: Δ=0.58 (control group Δ= 0.34)

    - Science and mathematics teachers working together to increase inquiry
        - Before treatment: Δ=0.38 (control group Δ= 0.41)
        - After treatment: Δ=0.6 (control group Δ= 0.34)

- Medium:
    - Mathematics teachers working on their own to increase inquiry
        - Before treatment: Δ=-0.01 (control group Δ= 0.18)
        - After treatment: Δ=0.29 (control group Δ= 0.18, an improvement)
    - Science teachers working on their own to increase inquiry
        - Before treatment: Δ=0.56 (control group Δ= 0.18)
        - After treatment: Δ=0.23 (control group Δ= 0.18, a decrease)
    - Science and mathematics teachers working together to increase inquiry
        - Before treatment: Δ=0.46 (control group Δ= 0.18)
        - After treatment: Δ=0.24 (control group Δ= 0.18, a decrease)
- High:
    - Mathematics teachers working on their own to increase inquiry
        - Before treatment: Δ=-0.13 (control group Δ= 0.02)
        - After treatment: Δ=-0.02 (control group Δ= -0.16, an improvement)
    - Science teachers working on their own to increase inquiry
        - Before treatment: Δ=0.05 (control group Δ= 0.02)
        - After treatment: Δ=-0.02 (control group Δ= -0.16, an improvement)
    - Science and mathematics teachers working together to increase inquiry
        - Before treatment: Δ=0.19 (control group Δ= 0.02)
        - After treatment: Δ=0.07 (control group Δ= -0.16, an improvement)

Where are we now, and some attempts to fix some of the indicated problems.

The KIDS program is now in its sixth year, with matching funds from the university. It is a partnership between the J. William Fulbright College of Arts and Sciences, the College of Education and Health Professions and the College of Engineering. This year 10 graduate fellows are working with 19 K-12 science and mathematics faculty. The program draws graduate students from science departments across the university, including physics, chemistry and biochemistry, biology, microelectronics and photonics, engineering, and mathematics. The K-12 faculty come to the program from Fayetteville, Springdale, Rogers and Bentonville schools. Graduate fellows spend approximately 10 hours each week team-teaching in the middle school classrooms. The same fellow now works with both the mathematics and the science K-12 faculty. The K-12 faculty each have “less fellow”, but the activities are developed as a team and integrated smoothly across both courses. Although analysis since beginning this pairing of K-12 faculty with a common fellow is far from complete, preliminary data indicate that benchmark scores will show continued improvement. It is anticipated that this will remove the decrease in mathematics perception. Anecdotally, student and parent attitudes appear to be quite positive.

So, what are the important lessons, and what are the warnings?

- Not in math, just in science: Interest in mathematics careers did not go up, but mathematics scores did.

- Hands-on is not the same as inquiry. This often gets lost.

- While we have not had the resources to do the research on the K-12 faculty who participated in the summer inquiry camps and went into teaching, without a fellow, anecdotally we are seeing improvements. They should be able to get the same learning gains, although the attitudes about careers in STEM may not be as strongly impacted. Ma (1999) found that participation in advanced mathematics in grades eight to twelve was strongly correlated with students' prior achievements in mathematics. Positive attitudes towards mathematics were correlated to participation in advanced mathematics but only at the higher grade levels. So, perhaps getting them to be successful early will get them into the advanced courses, where their attitudes will become more positive, anyway.

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Preparation for Fractions
The Role of Units in Learning Fractions

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Introduction

Middle school students need to be prepared to learn fractions through work in elementary school that lays a solid foundation for fractions in the spirit of how addition lays a foundation for multiplication. In turn, middle school mathematics needs to build on such a foundation to improve the current poor status of students' understanding of fractions and their applications. Units are a critical organizing concept in elementary school preparation for fractions and in middle school instruction. This concept is also important in applications of whole number arithmetic. Further, attention to units in mathematics classes builds a natural link between mathematics and science instruction.

A few words about fraction first. Fractions have assumed a central role in the workplace. Whether on production lines or managers' desks, many of the numbers one encounters in business today are percents and rates—error rate, interest rate, employment rate, productivity level, etc. Thus all citizens today need to know how to use and interpret fractions. Whole number arithmetic, which once was all the mathematics used in most jobs, is now performed in the workplace by machines for the sake of record keeping as well as accuracy. Whole number arithmetic is still needed for simple mental calculations throughout daily life, but increasingly its primary importance is as the mathematical foundation for future mathematical learning. The next major mathematical topic after whole number arithmetic is fractions. International comparisons like TIMSS reveal that too many U.S. students have trouble making the transition from whole number arithmetic to fractions. Thus, it is natural that mathematics in early grades should be taught with greater attention to preparing students for fractions. The widely praised 2006 NCTM Curriculum Focal Points report emphasizes preparation for fractions in elementary school.

As emphasized in the 2008 National Mathematics Panel report, students who do not master fractions—what a fraction is, how to calculate with fractions and apply them—face a tremendous hurdle in trying to master algebra or subsequent college mathematics.

A number of mathematics educators as well as several mathematicians have given considerable thought to the role of units in studying fractions. This essay builds heavily on their efforts, especially those of the Rational Number Project participants (see www.education.umn.edu/ rationalnumberproject), Susan Lamon (e.g., [Lamon, 2006]), Les Steffe (e.g., [Steffe et al., 1988]) and H H Wu ([Wu, 2002]). It also draws on the development of fractions in Singapore and Japan elementary mathematics curricula. This essay grew out of discussions at a workshop on fractions at the Park City Mathematics Institute in July 2006 that was supported by an NSF grant to the Mathematical Association of America titled Preparing Mathematicians to Educate Teachers. The Park City participants consisted of mathematicians, mathematics educators, and mathematics teachers.

Unit Fractions

Because fractions are much more complicated than whole numbers, intuition cannot be counted to develop an understanding in young students' minds of what fractions are, much less how to calculate with them. The standard initial definition of a fraction that is used in other countries, especially high-performing Asian countries such as Japan (Takahashi [2004]) and Singapore (Singapore Math [1997]), is:

A fraction is a number that is an (integral) multiple of some unit fraction.

In mathematical notation, we mean a number of the form $k(1/l)$, for whole numbers k, l ($l > 0$). This definition assumes that students have first developed a good understanding of what a unit fraction is. Writing out a fraction, such as ¾, as "three fourths" emphasizes the role of units in fractions. Unit fractions are discussed shortly. Defining fractions in terms of unit fractions avoids a major conceptual problem, namely, establishing that a fraction is a number. That burden now falls to unit fractions. A second advantage of defining fractions in terms of unit fractions is that this approach separates the study of the numerator and the denominator of a fraction. Numerators are standard counting numbers, while denominators are a totally new quantity—they are ***units*** defined in terms of reciprocals. This is the reason for focusing on unit fractions and units generally.

Because so many U.S. students never move beyond thinking of a number as a counting number, we should not be surprised that students mindlessly memorize operations with fractions in terms of the integers in numerators and denominators without knowing what a fraction is. As a consequence, they will often assert that 1/3 + 1/5 = 1/8.

On the other hand, a child's first understanding of a number will necessarily be as a counting number and multiplication is naturally introduced as repeated addition. Thus the pedagogical goal must be to help students extend, rather than abandon, these initial understandings of a number and multiplication; Les Steffe calls this critical process reconceptualization. (Students face this challenge over and over as they advance in school mathematics.)

Unit fractions, such as ¼, are a natural precursor to general fractions. Unit fractions arise frequently in day-to-day conversations—a quarter (the coin), a quarter after 5 o'clock, a quarter of a mile down the road, a quarter of a cup of flour, a 1 ¼ inch screw, etc.

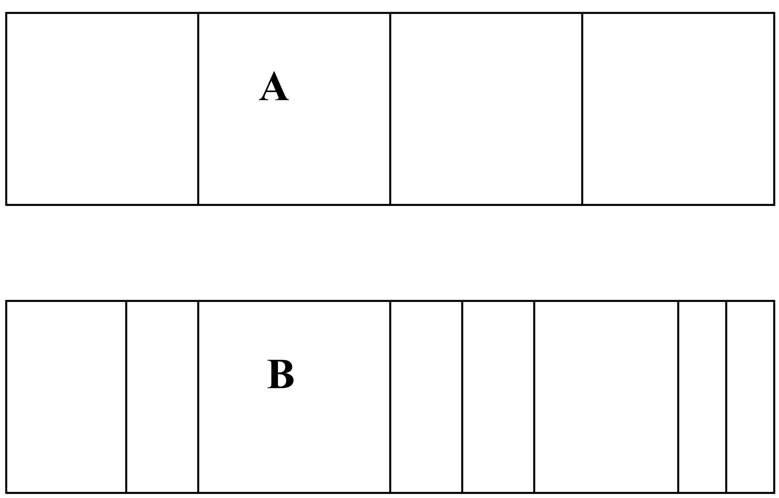
Familiarity with unit fractions also grows from measurement problems, some of which can be associated with science instruction. Unit fractions arise naturally in measuring length, time, money, and later area and volume. Note that the transition from multiplication by whole numbers, i.e., repeated addition, to multiplication by fractions is a natural extension in linear measurements: if bricks are 8 inches long, how would long would a row of 3½ bricks be?

Measurement should also include problems in converting units such as a fraction of a foot to inches. The most important of these contexts is length as measured with a ruler, a concrete version of the number line.

As students start formal work with fractions, e.g., equivalent fractions and finding common denominators to fractions, word problems with unit fractions can continue. An example is the problem of how high a pile of 4 notebooks would be if each notebook is 5/8” thick. The answer would first be found in terms of 1/8ths and then converted to whole inches. A more advanced, inverse version of this problem would be, how many notebooks that are 5/8” thick can be piled into a box that is 2½ feet deep.

For young children, unit fractions evolve from counting numbers: a pie divided into fourths is split into equal pieces which when counted amount to 4. To give a sense of the cognitive challenge students face in moving beyond this image of unit fractions, I cite a scene from a demonstration class of fifth graders led by D. Ball at the Park City Mathematics Institute in summer 2006. When students were asked to go to the blackboard and highlight 1/8th of a collection of 24 circles that had been drawn, one student first divided 8 into 24 to get 3, and then he proceeded to partition the set of 24 circles into groups of 3. He had to check that 8 groups of 3 balls completely partitioned the set of 24 balls before being able to say that 3 balls were 1/8 of the set of 24 balls. That is, 1/8 of a set did not exist in his thinking independently of the other 7 1/8’s of the set.

Here is another example of the trouble that students have in moving beyond the equal division model of a fraction [Tzur, 2006]. Consider the following two rectangles, both with the same dimensions. The upper one is divided into 4 equal sections. The lower one is divided into 8 unequal sections. One is told that section A in the upper rectangle is the same size as section B in the lower rectangle. The question is, what fraction of the lower rectangle is section B?



Many middle school students will assert that section B is our fourth of the upper rectangle but that one cannot tell what fraction it is of the lower rectangle. The same response is given by some middle school teachers.

Unit

To illustrate the role of units in working with fractions, consider the following problem:

Some balls are taken from a box and 15 balls are left. This number 15 is three quarters of the number of balls that started in the box. How many balls started in the box? (*)

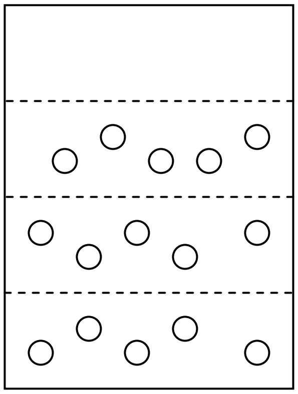
The reasoning for solving this problem involves two types of units. The problem can be restated: if we know 3 fourths of a quantity, what is 4 fourths of the quantity. The key is to think in terms of fourths. If one fourth is our unit, then the problem comes, if three units equal 15, what do four units equal. The natural intermediate step in the solution is to determine what one unit equals. We get that one unit is 15/3 = 5, balls, and the boxful of 4 units equals 4 x 5 = 20 balls.

While fourths were the units for initially analyzing the problem, 5's were the units involved in determining the final answer. One could say that one unit equals our fourth of a boxful, and then restate that unit as equal to 5 balls. One could also look at these two units as a ratio: 5 balls per fourth of a boxful. Analyzing relationships between two or more units underlies the solution of almost all real-world problems involving fractions. This analysis is a natural extension of problems involving one unit, which underlie most simple word problems involving whole number multiplication and division. For example, given that one box holds 5 melons (that is, one unit is 5 melons), one may ask how many melons are in 4 boxes, or ask how many boxes are needed to hold 20 melons. Many educators refer to the (implicit or explicit) use of units to solve such a problem as multiplication reasoning. Such reasoning is a prerequisite for fraction problems.

Problem (*) could be modeled algebraically as (3/4)x = 15 and solved for x to obtain x = 15/(3/4), with the right-hand side computed with the invert-and-multiply rule for division by fractions. That rule, of course, yields the same calculation as in the previous analysis: divide 15 by 3 and multiply the result by 4 (or the order could be inverted). Students should understand the reasoning that leads to the invert-and-multiply rule by working many problems like (*). Then they will think of that rule as simply a mental shortcut for this reasoning.

More generally, when students learn the algorithms for arithmetic operations on fractions, the algorithms need to be viewed as a concise way of working with previously studied problems involving unit fractions, similar to the same way with whole numbers that the multi-digit multiplication algorithm is seen as a concise way to perform iterated addition.

In East Asian countries, where elementary school children work with unit fractions and solve multi-step word problems, problem (*) is almost routine by 5^{th} grade. It is realistic to have the same expectations of U.S. 5^{th} graders, if U.S. curricula is laying the proper foundation in early grades. One important advantage for East Asian students is that their textbooks make much more extensive use of diagrams and other helpful figures to allow students to 'see' the right way to look at a problem. (The TIMSS 1999 Video Study [NCES, 2003] found that 83% of the problems in 8^{th} grade math lessons in Japan used diagrams or drawings while the percentage in the U.S. was just 26%.) For example, when problems like (*) are first encountered, students should see a diagram like:



to point them towards the solution. Such diagrams would seem to be particularly powerful in helping students organizing their thinking about problems that involve units. On the other hand, students must in time abstract the thinking that is initially motivated by diagrams.

Many rate problems have a similar structure to (*). For example,
If a car going at a constant speed covers 48 miles in ¾ of an hour, how far will it go in one hour; or equivalently, how fast is it going (in miles per hour).

First one must focus on measuring time in fourths of an hour. Then one switch to the dual unit of 16 miles, the distance traveled in a fourth of an hour.

Of course, problem (*) and the car problem would be studied after simpler problems are worked, such as:

Find 3/4ths of 20.

Not only is the role of fourths more clear-cut in this new problem, but the intermediate step of determining what one fourth equals involves the standard way of dividing a given amount into fourths by dividing by 4.

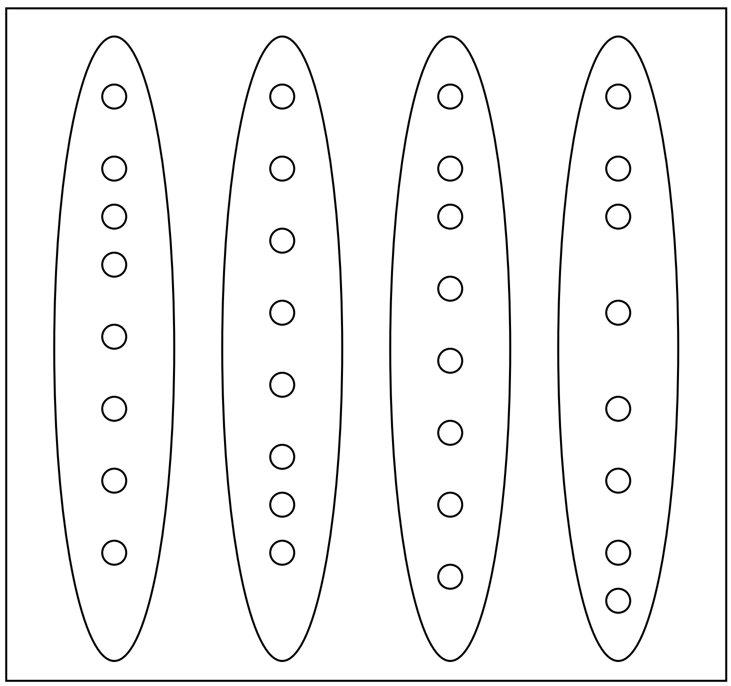
Another way to prepare for problem (*) and the associated car problem is to model the same arithmetic calculations with a problem without fractions. For example:

If 3 boxes hold 15 balls, how many balls will 4 boxes hold? and

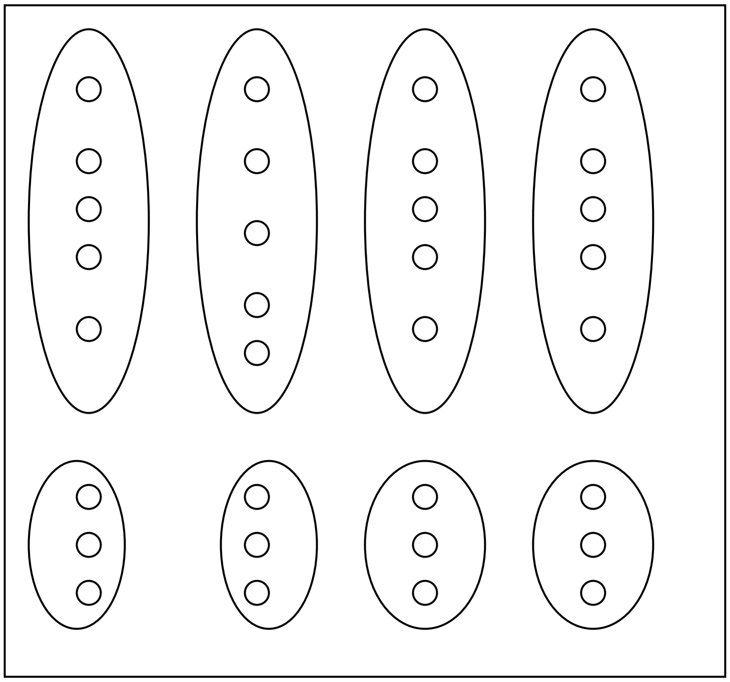
If a bicycle going at a constant speed goes 48 miles in 3 hours, how far will it go in 4 hours?

Again, the dual units are much easier to find here: the unit of one box must be equated with the contents of the box, 5 balls; and the unit of one hour equated with the distance traveled in one hour, 16 miles.

Let us briefly touch on the role of units in beginning whole number arithmetic. Skip counting, e.g., 2. 4. 6. 8, etc. is counting with a unit larger than 1. Skip counting evolves into multiplication. The distributive law is first introduced in Singapore schools in second grade as a tool for simplifying multiplication with digits larger than 5. The underlying idea is that a large unit in skip counting can be replaced with two smaller units. For example, to determine 4 x 8, that is, the sum of 4 eights, one can start with the diagram below:



Then one reorganizes the groups of 8 balls as groups of 5 balls and 3 balls to get



A student is thus prompted to solve 4 x 8 as 4 x 5 + 4 x 3 (each product obtained by skip counting.

We close this section by mentioning a pedagogical strategy, developed by Herb and Ken Gross, for understanding the relationship between numbers and units. They call numbers 'adjectives' and they initially use these 'adjectives' only in the context of modifying a 'noun', such as 5 pencils or 2/3rds of a pie. The nouns are extended to include units of measurement and units defined in terms of other adjective-noun pairs such as 4 (boxes of 500 pencils) and 5 (eighths of an inch).

Converting Between Units

One of the critical mathematical building blocks for working with fractions is equivalent fractions, different fractions that represent the same rational number, e.g., ½ or 2/4 or 5/10 or 13/26, etc. Equivalent fractions are often the first topic discussed when the formal study of fractions begins in around 4th grade, after which addition of fractions can be presented. However, the general topic of equivalent representations of a number arises repeatedly in measurement problems, e.g., ½ foot = 6 inches, or 50 cents = 10 nickels = 5 dimes = 2 quarters = ½ dollar, as does the issue of finding a new, common representation for adding quantities in different units, e.g., adding 1/3 foot + ¼ foot by converting to inches, or adding 2 dimes and 1 quarter by converting to cents. Simple applications of equivalent fractions can also be studied: measuring out 1 1/2 pounds of candy in different ways given bags of candy weighing ¼ lb., 1/8 lb. and 1/10 pound.

Equivalent fractions are a particular case of a more general mathematics topic, namely converting a number expressed in terms of one unit to another unit. Finding a new unit for representing different quantities arises in word problems involving multiplication and division.

Consider the problem:
A brick is 8 inches long. How many bricks must be placed end to end to reach 10 feet?

First we express the length of 10 feet in terms of inches—120 inches— using the conversion rule 1 foot = 12 inches. This is the first change of units. Then we convert the length in inches into another unit, brick lengths, using the conversion rule 1 brick length = 8 inches. The first conversion involved a multiplication and the second a division.

The following solution strategy follows the spirit of unit fraction examples in the previous section. After noting that one brick length is 2/3rds of a foot, one converts the total length from feet to 1/3rds of a foot. This is an easy conversion—multiply by 3-- to keep straight in one's mind, and work with unit fractions continually reinforces such conversion strategies. So now the length is 30 thirds of a foot. Since each brick is 2 thirds of a foot long, we need 30/2 = 15 bricks.

This problem can be simplified if one knows how to compute with fractions. There is the following condensed solution using a single change of units: 1 brick length = 2/3rd of a foot. Now the change of units requires dividing 10 by 2/3. However, the division by 2/3rds can be avoided if we restate the conversion as feet to brick lengths: 1 foot = 1 ½ brick lengths. Then 10 feet = 1 ½ x 10 = 15 brick lengths.

This problem illustrates the fact that any time one performs multiplication or division in solving an applied problem, one is explicitly or implicitly converting units. Thus, more attention to units and change of units in elementary school mathematics instruction seems critical to improving students' mathematical problem-solving skills as well as providing the proper foundation for learning fractions.

As a pedagogical aside, when students are ready to study such a problem, it is very valuable to have a class discussion about different ways to solve the problem (the solution involving division by 2/3 would be too advanced). Looking at multiple ways to solve such problems highlights the role of units and shows how a calculation with a fraction can frequently be recast as a short cut for a two-step calculation involving a multiplication and a division with whole numbers.

Let us next consider a word problem involving three units, a problem more complicated that most U.S. 5th or 6th graders can currently solve. It is the first word problem to appear in the 5th grade Singapore mathematics textbook [Singapore Math, 1997]:

> Mrs. Li bought 420 mangoes for $378. She packed them into packets of 4 mangoes each and sold all the mangoes at $6 per packet. How much money did she make?

The initial units that appear in the problem statement are mangoes and dollars. Later in the problem statement, packets enter. We need to convert units for measuring mangoes from individual mangoes to packets of 4 mangoes. Given that 4 mangoes go into packet, we divide

420 by 4 to obtain 105 packets. Now we convert our units for measuring mangoes from packets to value in dollars. The conversion factor is that one packet yields $6 dollars, and so we multiply for this conversion to obtain a value of 105 x $6 = $630. Note that the conversion factor naturally occurs as the second term in both the multiplication and division conversion step. Finally, we have cost and income in the comparable units, dollars, and so the amount of money made in this activity, $630 - $378, can be computed.

Another way to approach this problem is to look for a way to convert directly from units of mangoes to units of money. This conversion requires determining a rate of income per mango. Since 4 mangoes in a packet sell for $6, we obtain a rate of $6/4 (= $1½ per) per mango.

In middle school, greater proficiency in converting between units can be used not only to solve harder word problems but also to gain insight into multiplication and division of fractions. Consider the calculation

2/3 x 4/5

Interpreting 2/3 as 2 thirds [=2(1/3)], we first need to find 1/3 of 4 fifths. We are initially stuck because 1/3 of 4 is not a whole number. We change to new unit that is sure to work, namely 1/(3x5). So we convert 4 fifths to 12 fifteenths [= 12(1/15)]. We can find 1/3 of 12 fifteenths by dividing 12 by 3; it is 4 fifteenths (4/15). Finally we multiply this amount by 2 to find 2 (1/3) = 2 x [4(1/15] = 8/15. Diagrams can help with this problem. For example, 4/5 could initially be depicted with a rectangle partitioned by horizontal lines into 5 equals parts with the lower four parts shadowed. Then the rectangle could be subdivided with 3 vertical lines into 15 equals parts. One third of the 12 shadowed parts is found, etc.

Students' knowledge of unit problems can also be used to revisit whole number addition and subtraction from an advanced viewpoint and realize the role of conversion among decimal units in the standard algorithms of arithmetic. The place value notation is now seen as a system of decimal units. The key steps of carrying in addition and borrowing in subtraction involve converting between consecutive decimal units. The standard multiplication and division algorithms can be studied in terms of how they combine partial computations in different decimal units. As an aside, students should find decimal numbers (e.g., 35.26) and order-of-magnitude approximations much easier to understand if they have previously had the extensive study of units that we are advocating.

Concluding Remarks

The search for ways to better prepare U.S. students to learn fractions has led the authors to a greater appreciation of the role of units throughout K-8 instruction. A focus on units can help unify reasoning for solving many word problems with whole numbers as well as with fractions.

As more attention is given to reasoning with units, it seems natural that school mathematics curriculum development may involve more educational collaborations with physical scientists and science educators, since units play such an important role in science.

We close with a concrete example of the challenges in implementing the program outlined above. We refer again to the model class of Deborah Ball's mentioned at the end of section 2 where students were asked to find one eighth of 24 balls drawn on the blackboard. One student divided 8 into 24, and, based on his answer of 3, partitioned the 24 balls into 3 groups of 8 each. Next he marked one ball in the first group of 8. However, the student then stopped and gave 1 as the answer. A cognitive specialist watching the students speculated what had gone wrong. Like many other students of his age, this student had trouble keeping track of more than two units at one time. He reorganized the problem of finding $1/8^{th}$ of the whole group of 24 by first breaking 24 into 3 groups (units) of 8's. He then determined what $1/8^{th}$ of a group of 8 was, but had lost track of the relationship between the original group of 24 and the group of 8. Keeping track of multiple units is an example of a critical cognitive skill that mathematicians probably take for granted. Thus, to better prepare students to learn fractions, one needs not only to understand the proper mathematical development of underlying concepts, such as units, but also to understand the hurdles that students face when they try to learn these concepts.

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Developing and Sustaining a Science and Mathematics Education Community for Action Research to Explore Mathematics Infusion Into the Science Classroom

Arthur L. White and Donna F. Berlin

A variety of terms, definitions, and models have emerged since the establishment of the concept of "action research" over 50 years ago by Kurt Lewin (1952). He described a spiral of circles of research beginning with a description of the field of action, moving to an action plan, followed by an action step, and finally the evaluation of the plan and action leading to a new action plan and a repeat of the cycle. Many educators have used this continuous cycle as the framework for their action research (Berlin & White, 1993; Feldman & Minstrell, 2000; Kemmis & McTaggart, 2000; Watt & Watt, 1993).

Today, action research remains as a powerful tool to connect theory, research, and practice as well as researchers with practitioners. Terms such as classroom-based inquiry and practical inquiry affirm the role of the teacher; however, we believe that action research is a collaborative endeavor that involves a broader community including the school district and higher education. Our experience and research since 1987 has suggested that a collaborative community of teachers (preservice and/or inservice), school district administrators and supervisors, and university faculty are necessary to successfully initiate and engage in action research to solve educational problems, improve classroom practice, and promote professional development. For us, action research is defined as "systematic and recursive inquiry and reflection in a collaborative learning community directed toward the understanding and improvement of practice" (Berlin, 1996, p. 73). The purpose of this article is to describe the requisites for prospective and practicing science and mathematics teachers to be able to engage in and benefit from action research to explore mathematics infusion into the science classroom.

Our History With Action Research

The model for action research in this article has grown overtime from a variety of efforts. These efforts include (a) the *Academic Challenge Action Research Program* which was a collaboration between self-selected inservice K-8 teachers and education researchers at a major Midwestern university from 1987-1993; (b) a group of teachers in San Francisco, CA who participated in a workshop entitled Action Research: Solving Educational Problems to gain the knowledge and skills to conduct action research in their classroom related to the implementation of a new science and mathematics program; and (c) a group of teachers in Elkhart, IN who also experienced the action research workshop and conducted action research projects using different science and mathematics textbooks to inform the final textbook selection process. The evidence from these projects with teachers suggests that when engaged as professionals and provided with appropriate year-long support through established collaborations and resources, teachers will assume the role of professionals as innovators/researchers and proponents for the use of research-based evidence to improve practice.

After numerous experiences with teachers as they engaged in the process of action research, an opportunity to extend this model to preservice teachers emerged with the restructuring of the teacher education licensure program at a large Midwestern university. In 1996, the Mathematics, Science, and Technology Education (MSAT) Master's of Education Program was implemented as a five-quarter program leading to teacher certification and a Master's of Education degree (M.Ed.). Two unique elements of the program are: (a) the integration of science, mathematics, and technology education through specially designed, team-taught content and methods courses and (b) a focus on current theory and research culminating in an action research project designed and implemented by the preservice teachers. These elements have guided the development and implementation of the courses as well as field and clinical experiences for the MSAT M.Ed. Program.

To prepare teachers to design and implement their action research projects, analyze and interpret their findings, and write final action research reports, they complete a course, entitled Action Research Methods, during the first summer of the program. This course includes literature search strategies, basic concepts of research design, methods of data collection and analysis, and reporting results related with both quantitative and qualitative research paradigm perspectives. Opportunities to experience the benefits of a mixed methodology are provided to encourage teachers to use the methodology or methodologies that best answer their research question(s). Throughout the academic year, the teachers are encouraged to consult with the instructors of the summer action research course or their faculty advisors as they design and implement their action research projects, collect their data, and analyze and interpret their findings. Generally, the teachers implement their action research project sometime during the academic year. Inservice teachers often enroll in an optional course in the spring quarter to receive additional help with the data analysis and interpretation. During the summer quarter of the program, the teachers focus upon the writing of their final Action Research Reports. The final Action Research Report is evaluated by their faculty advisor and a second faculty reader and serves as one of the exit requirements for the Masters' degree. As a culminating activity, the teachers share their action research reports.

Berlin-White Action Research Model (BWARM)

Our experience with and evaluation of these inservice (Berlin & White, 1993) and preservice programs (White and Berlin, 2006) laid the groundwork for the development of our six-step model for conducting action research, the Berlin-White Action Research Model

(BWARM). Although our action research model is presented in a linear fashion, this process is more cyclical with opportunities to revisit the six steps throughout the process.

1. Conceptualization of the problem-question of interest, question of focus, research question

The focus of the action research may be a new or innovative teaching technique; it may be in response to an area or topic of teaching that has been problematic for students; or it may be to document something that the teacher researcher believes works and wants to provide evidence to support these intuitive perceptions. It may focus on the potential adoption of a new textbook series or a new curriculum program with an emphasis such as the infusion of mathematics into the science classroom. The focus of the action research should be worthwhile, focused and manageable, realistic, and of interest to the teacher researcher. It should be related to normal practice so it is not an add-on to the already busy teaching schedule but rather it should provide a value-added component relevant to current practice.

2. Review of the literature

We encourage our teacher researchers to review theoretical, research, and practice-based literature. The theoretical literature includes beliefs and perspectives associated with student learning and development. The teacher researchers often cite theorists such as Ausubel, Dewey, Piaget, and Vygotsky to develop a theoretical framework for their action research. A review of the relevant research can help to refine the problem or question, guide in the development of procedures and methodology, provide possible tools (e.g., instruments, interview questions, surveys) to collect data, and provide a general understanding of the knowledge base related to their problem or question. The practice-based literature should ground the action research in national and local standards-based documents as well as suggest new or innovative materials and/or methods for teaching and organizing the classroom environment.

3. Implementation of the classroom action plan

This step in the action research process involves the implementation of a teaching technique or strategy in the classroom that is unique to the individual teacher researcher or a collaborative group of teacher researchers and is directly aligned with the problem or question of interest. Some of the science and mathematics classroom action plans developed by our students include: heterogeneous and homogeneous (gender or ability levels) cooperative learning groups, history of science, journal writing, newspaper headline issues, and the use of the internet (e.g., webquests).

4. Data collection

As a focus on student learning outcomes is central to practice, all of our teacher researchers develop an achievement test (often in a pretest and posttest format). Publishers often include achievement tests to accompany their textbooks and these can be used as is or modified to collect achievement data. Alternative assessments along with rubrics also can be used. Also, we encourage the teacher researchers to collect attitudinal data as student attitudes are important and related to both student performance and career aspirations. The literature review can provide examples of appropriate Likert-type surveys (strongly disagree to strongly agree) and potential interview questions to use or modify to identify student attitudes.

The teacher researchers conduct validity and reliability analyses on all the instruments used to measure student outcomes. These analyses (e.g., peer checking for face validity and Cronbach's alpha for internal consistency reliability) are employed to ensure that these instruments measure what is intended and that they are precise and accurate measurements specific to their students.

5. Data analysis

To address questions of interest that involve a quantitative analysis, we developed a *Guide for Action Research and Basic Research Data Analysis Using SPSS*. This manual provides easy to use step-by-step instructions for topics such as input and saving of data, recoding data and building scales, reliability (for instrument development), transformations and computations, paired-sample *t*-test, Multivariate Analysis of Variance (with and without Repeated Measures), and Pearson Product-Moment Correlations. As new versions of SPSS are published, we revise and update this manual. The current manual is written for SPSS 17.0. We encourage practicing teachers to use the school and district resources which often include individuals with technical and research expertise to support teachers as they engage in the analysis and interpretation of their data.

To address questions of interest that are more concerned with the natural context and process and strive to be sensitive to individual perspectives, qualitative data collection and analysis procedures are reviewed. Guidelines to collect, organize, analyze, and interpret qualitative data are provide to triangulate data and ensure trustworthiness and credibility.

6. Reporting of results, including implications for classroom practice and future research

Because many of our teacher researchers are enrolled in university courses and programs during the action research process, the format for their action research project report is structured and comprehensive. We provide our teacher researchers with sample action research reports written by teacher researchers who previously participated in our courses to serve as a guide for their writing. Some websites that include sample action research reports include:

http://journals.library.wisc.edu/index.php/networks (an online journal for teacher research) and http://educ.queensu.ca/~ar (action research reports from B.Ed. and M.Ed. students at Queen's University, Kingston, Ontario, Canada).

The essential elements of an action research report include the introduction, a statement of the questions/problem, a description of the research process, data analysis, interpretations and conclusions, and next steps. The reporting of the action research is very important for a number of reasons, including: (a) refining and crystallizing the research, (b) sharing important findings, and (c) improving teaching and learning. Moreover, dissemination of action research affirms that action research is an important, worthwhile, and valuable professional endeavor that can lead to teacher self-efficacy and empowerment. Our teacher researchers not only complete written action research reports but they also present their work orally in a conference-like setting which includes university faculty, other teacher researchers, and administrators.

We believe our model for action research is somewhat unique in two ways. First, we insist that our teacher researchers review the literature after deciding upon an initial problem or question of interest or focus. Second, we encourage our teachers to consider a mixed methodology approach when appropriate—using both quantitative and qualitative procedures to better understand what is happening in the classroom and determine what might improve teaching and learning in that context. Related to both qualitative and quantitative methodologies, we encourage practicing teachers to explore school, district, and higher education resources to locate individuals with expertise to help analyze and interpret their data.

Conclusion

For practicing science and mathematics teachers to be able to engage in and benefit from action research, collaboration among teachers, school administrators, and teacher educators is necessary (Goodenough, 2003, 2004; Larson, Mayer, Kight, & Golson, 1998; van zee, 1998; van Zee, Lay, & Roberts, 2003). Each has a unique but synergistic role in encouraging, facilitating, and supporting action research in the science and/or mathematics classroom.

Science and mathematics teachers should be action researchers. Teachers should be provided "… opportunities to learn and use the skills of research to generate new knowledge about science and the teaching and learning of science" (National Research Council, 1996, p. III-18). They should identify the research problems or questions that emerge from their practice and are of interest to them. Action research should be a part of teacher professional development–both teacher preparation and teacher enhancement. Ideally, teacher education should include courses related to action research and opportunities to engage in action research. Teachers can be prepared for the action research process through university courses/workshops or school district inservice opportunities. A key element is continuous support throughout the action research process through seminars and individual consultation. Science and mathematics teachers should disseminate the results of their action research to other teachers and administrators both within and beyond the district.

Our penultimate goal is to develop an action research community of teachers, administrators, and higher education faculty who recognize the benefits of action research–the value to document what works and advance classroom practice and the power to enable classroom teachers to make research-based decisions as they build self-efficacy and develop professionally. Teachers should be provided with release time and resources, both human and material to encourage, nurture, and sustain their capacity and confidence to conduct meaningful action research.

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Appendix C

Participant-developed research proposals

Math Infused Greenhouse Project (MIGP)

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Goals of Math Infused Greenhouse Project (MIGP)

The mission of MIGP is to develop and research a high-quality innovative program to: 1) to assure all students the opportunity to learn significant STEM content; 2) to support STEM learning by seeking opportunities to integrate content learning; and 3) to enhance STEM learning through effective integration of a STS topic. To address these challenges, the Project will:

Produce a generalizable methodology of STEM learning that can lead to the development of an integrated STEM curriculum.

Conduct research into 1) learning acquired through content integration; 2) changes in student attitudes toward content learning based on an integrated curriculum; and 3) the adaptability of the Project model to diverse student populations.

Develop a 3 lesson prototype curriculum that promotes acquisition of important content knowledge by students through STEM integrated activities in the context of a STS area (Climate Change), addressing middle school STEM standards, and includes embedded formative and summative assessments of student understanding.

Evaluate, publish, and disseminate models, methods, products, materials, and results.

Key Learning Objectives Relate to:

Science (based on NCTM *Focal Points*)

- Benchmark 1: The student will develop scientific habits of mind
- Benchmark 2: The student will understand the impact of human activity on resources and the environment
- Benchmark 3: The student will understand that human populations use natural resources and influence environmental quality
- Benchmark 4: The student will understand the effect of natural and human-influenced hazards

Mathematics (based on NCTM *Focal Points*)

- Number and Operations and Algebra and Geometry: Developing an understanding of and applying proportionality, including similarity.
- Number and Operations and Algebra: Developing an understanding of operations on all rational numbers and solving linear equations.
- Measurement and Geometry
- Number and Operations
- Data Analysis
- Probability

Methodological Overview

MIGP will develop, research, and evaluate an instructional model and a prototypical three lesson instructional sequence integrating mathematics and science content in the teaching of Climate Change. The lesson sequence will emphasize the problematic nature of the underlying mathematic understanding that is necessary to reach scientific conclusions concerning climate change claims. The sequence will contextualize key scientific concepts described in the *Science for All Americans* (SFAA) and *Atlas of Scientific Literacy* as well as the content focal points identified for grade 7 by the NCTM *Focal Points* document.

Development of Materials

A quick look at the popular press, blog sites, wikis, and other media clearly show that there is a growing concern and action about greenhouse gases, global warming, climate change, sustainability, and ultimately the fate of modern society. These concepts are complex and inter-related. In recognition of these concerns, NOAA organized a three-day workshop in April 2007, *Climate Literacy Research to Develop Weather and Climate Literacy Framework*, that included representatives from NOAA, NASA, Department of Commerce, and the US Climate Change Science Program's Communications Interagency Working Group (see www.climate.noaa.gov/education). The resulting document, Climate Literacy: The Essential Principles of Climate Sciences (February 2009) defines a climate-literate person as one who (p 2):

- Understands the essential principles of all aspects of the Earth system governing climate patterns
- Knows how to gather information about climate and weather, and how to distinguish credible from non-credible scientific sources on the subject
- Communicates about climate and climate change in a meaningful way
- And makes scientifically informed and responsible decisions regarding climate

The document goes on to identify 7 principles of climate literacy (http://www.climate.noaa.gov/index.jsp?pg=/education/edu_index.jsp&edu=literacy):

1. The Sun is the primary source of energy for Earth's climate system.
2. Climate is regulated by complex interactions among components of the Earth system.
3. Life on Earth depends on, is shaped by, and affects climate.
4. Climate varies over space and time through both natural and man-made processes.
5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.
6. Human activities are impacting the climate system.
7. Climate change will have consequences for the Earth system and human lives.

Embedded with the principles are a series of descriptors that define the dimensions of climate literacy. While much of the key ideas are science, an examination of the descriptors provides an indication of the mathematical knowledge implicit within the descriptors. Key words that relate to mathematical skills are: probability (expressed as likely and very likely), change over time, patterns, models/modeling, accurate predictions, variations, balance, measurements, uncertainty, economics, facts, and assumptions. Clearly, an underlying premise for climate literacy is the mathematical skill and knowledge to understand and act on the scientific knowledge. However, a review of the standards linkage chart to Project 2061, and the National Science Education Standards provided in *Climate Literacy Research to Develop Weather and Climate Literacy Framework* shows no explicit link to NCTM standards.

One of the findings from the STEM Conference was that mathematics instruction needs to be the explicit focus in an integrated science and mathematics lesson, not incidental (March 2009). Unfortunately, this point has not been realized in the new curriculum materials (e.g. Sneider, Golden, & Gaylin, 2008), climate literacy documents, and discussions on climate change, global warming, and energy and sustainability to name a few (e.g. Mann & Kump, 2008). A perusal of *Dire Predictions: Understanding Global Warming* (Mann & Kump, 2008) provides a quick summary of the evidence related to global warming and climate change as well as several well made illustrations to represent data; but even this assumes the foundation of the reader to understand probability of the projections, distinction in different units (ppm vs. ppb), uncertainty in measurement, and a sense of small and large numbers (what is 4000 tons of Carbon Dioxide?).

Other examples from popular literature do provide explicit mathematical instruction or at least a nod to the fact that not all of the population is skilled in mathematical reasoning and visualization. One clear example of connecting mathematics and science is shown by Richard A. Muller in his book, *Physics for Future Presidents: The Science Behind the Headlines (2008).* Muller is very clear about teaching the physics concepts within the text, but he also makes extensive use of Fermi–type questions (Taggart, Adams, et. al., 2007). For example, electric cars are being touted as the future of autos, but what of solar electric cars? On the surface it sounds good, but applying mathematical reasoning and tools shows that under the best of conditions, it takes one square yard to get one horsepower. A teacher from this point could take a class out to measure the area of a car and look up the horsepower of a car to examine the feasibility of this proposed solution. This then involves several of the mathematics standards related to measurement and estimation. Further examples in Muller's book relate to critically looking at the graphs that are circulated as evidence of global warming. While the graphs are clear, there are details that can be disguised or misrepresented by those who are skilled in this type of data representation. Again, there is a need for explicit instruction in teaching how to interpret a variety of representations of graphical data if we are to achieve the goal of a climate literate population.

David MacKay in his book *Sustainable Energy without the Hot Air* (http://www.withouthotair.com/), states the problem in a very clear manner (from the Preface):

> Twaddle [nonsense] emissions are high at the moment because people get emotional (for example about wind farms or nuclear power) and no-one talks about numbers. Or if they do mention numbers, they select them to sound big, to make an impression, and to score points in arguments, rather than to aid thoughtful discussion.

MacKay has hit on the crux of the problem – people embrace logical fallacies in their thinking rather than logic, science, and mathematics. The issues at hand to preserve society and manage climate change and its complex relations between science and society require not just knowing the jargon and facts, but being able to reason, make projections, and act. The importance cannot be understated, but it will require critical analysis to determine the leverage points and the most important aspects of mathematics to be taught as part of an integrated science and mathematics lesson on climate change, global warming, or energy. Specifically, learning how to use mathematics as a thinking tool is required, as the numbers are needed to guide and make decisions, not just rhetoric.

A review of the materials, and position documents *Understanding and Responding to Climate Change: Highlights of National Academies Reports* (NAS, 2008), and *Communicating and Learning About Global Climate Change: An Abbreviated Guide for Teaching Climate Change, from Project 2061 at AAAS* (AAAS Project 2061, 2007) indicates that lessons on climate change that develop proficiency in mathematics are needed. The intent of this project, a trial research study, is to identify key concepts that might have the greatest impact on student learning and understanding. The approach is not to develop a new curriculum, but specific activities that address mathematical underpinnings needed to reason and intelligentially discuss climate change and global warming. Teachers can use these activities that focus on mathematical development using the content related to climate change, global warming, and/or energy to interlace with their current curriculum.

The process used to identify the content was: a) select science topics that would be of potential interest to middle school students, b) select mathematics topics where additional instruction would aid in understanding the science and, c) select mathematics topics that naturally merge with the science topics. The specific mathematics focal points addressed by the lessons are: Number Operations and Algebra and Geometry, Measurement and Geometry, Number and Operations, and Data Analysis.

These criteria were used to develop three lessons: One dealing with Carbon Footprint, one with Estimations (Fermi Questions), and one with Graphical Analysis. Drafts of these lessons have been prepared and are included in Appendix A, B, and C for review. The research will provide a method of a) determining the relative merit and use of the lesson within a classroom context, and b) determining if the lesson with mathematical focus improves overall understanding of Climate Change and the Greenhouse Effect.

Research Design and Evaluation

Varied methods for assessing Project and student outcomes will be incorporated, including assessments of student content knowledge, expert reviews, teacher and student feedback, self-efficacy and attitudinal surveys, and observations. Both PI’s will undertake research and evaluation activities for MIGP. Both PI's will conduct professional development activities to instruct participating teachers concerning the integrated model of instruction as well as to offer content training around the topics addressed in the curriculum sequence. Participating teachers will agree to administer the Greenhouse Effect Concept Inventory (GECI) (Keller, 2007) as a pretest prior to instruction and as a posttest at the completion of the curriculum sequence; to allow for classroom observation during the teaching of the curriculum sequence; and to administer a social validity instrument to measure changes in student attitudes toward the implementation of the integrated curriculum sequence.

Formative Evaluation. A logic model, in which inputs, processes, outputs, and outcomes are mapped, will guide optimization of MIGP activities, outcomes, and products. The PIs will document and evaluate procedures used to create the curriculum sequence; and will ensure they alignment with pedagogical goals. To assess whether materials effectively promote learning, link to MIGP goals, and provide adequate teacher and student support, participants will be surveyed and interviewed. All materials will be examined by teachers, students, and relevant experts for utility, clarity, and relevance for the middle school classroom.

Research and Summative Evaluation. The research program, field testing, and the summative evaluation are balanced and student assessment data will be collected for three research conditions: 1) the *experimental* (hybrid) condition, where students are instructed using the curriculum sequence; 2) the *control* condition that involves students in normal classroom instruction; 3) *baseline data* will be collected to establish student achievement levels prior to commencement of the curriculum sequence.

Research will investigate the adaptability of the MIGP model; explore whether opportunities to learn content in an integrated curriculum focus lead to gains in understanding; and assess the social validity of the intervention.

Research questions will focus on operational design; on exploration of relevant theoretical questions connecting integrated STEM learning; and on adaptability as follows: 1) Does the MIGP model lead to greater enhancement of content knowledge, design products, and improved attitudes related to STEM learning than use of traditional classroom instruction models? 2) Is there differential impact on learning across the three conditions related to student background characteristics (e.g., gender, disability, and prior academic achievement).

The experimental condition testing will involve 6 teachers classrooms teachers (3 each from New York State and Kansas) with an average of 20 students each (n = 120 students). The other two conditions will ask the same teachers to present relevant content to another section of students (n=120). Baseline data will be collected from all 240 students involved in the MIGP study to allow for comparison of current student achievement prior to either condition. For each research condition, data will be collected in six assessment domains: <u>student variables</u> (gender, age, disability); <u>teacher/school context variables</u>; <u>content knowledge</u> (pre-post assessments of climate change knowledge assessed through the GECI; affective assessments (pre-post attitudinal ratings about the STEM learning); process measures of engagement (observational data in participating teachers classrooms).

Data will be analyzed using a variety of multivariate statistical analyses. The research and summative evaluation will identify not only how effective the MIGP curriculum sequence is in promoting student learning and affective changes but also for which students and under what conditions they produce the strongest outcomes. These results will inform curriculum revision and expansion as well as contributing to new knowledge related to the use of integrated STEM curricula.

Plan for Classroom Testing and Validating Materials

A three-phase classroom-testing procedure will optimize the quality of the materials. Draft materials will be 1) microtested with small groups of teachers during professional development activities to allow for the understanding of teachers interpret the materials and to forecast how students may interact with the materials, 2) field tested by 6 teachers under two conditions; and 3) revised based on participating teachers input. All resources and materials will be reviewed and validated by disciplinary and pedagogical experts. Developers will conduct the **microtest** with participating teachers to ascertain how clearly course components are understood, how well skills are defined, and if key ideas are expressed clearly. Participating teachers will **pilot test** materials in 12 classes with diverse student populations (including children with disabilities) in classrooms in New York State and Kansas.

Logic Model MIGP Curriculum Sequence

Assumptions:
1. The MIGP curriculum sequence will have an impact on participating students' understanding of climate change.
2. The MIGP curriculum sequence program will have a positive impact on participating students' attitudes toward mathematics and science.
3. The activities used during sessions will influence further development of integrated STEM learning content.

Goals:
- Encourage students to explore the topic of climate change through an integrated STEM curriculum and gain a new perspective of the greater abstractness and complexity;
- Positively influence participating students' attitudes toward mathematics and science based on the integration of STEM content; and
- Encourage participating teachers to integrate STEM learning experiences in their existing curricula.

INPUTS	**OUTPUTS**		**OUTCOMES**		
	ACTIVITIES	**PARTICIPANTS**	**SHORT TERM**	**MEDIUM TERM**	**LONG TERM**
• Funding from Center for Technological Literacy. • Training of MIGP instructors	• Develop integrated STEM learning activities focused on climate change. • Develop assessment instruments to measure the impact of activities on students engaged in MGIP activities. • Conduct week-long intensive training of participating teachers in use of MGIP activities.	**Primary Audience:** Students in the classrooms of teachers participating in MGIP activities. **Secondary targets:** Classroom teachers involved in MGIP activities who will integrate STEM learning in other portions of their curriculum.	*Increased understanding of climate change.*	*Increased appreciation of the role of integrated STEM curriculum*	*Further development of integrated STEM learning modules.*
			OUTCOME MEASURES		
			Pre/post test analysis of content knowledge.	Positive responses to social validity measure administered at completion of MGIP activities.	Participating teachers will engage in development of integrated STEM learning experiences to be introduced into their existing curricula.

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APPENDIX A Calculating Carbon Footprint

Calculating Your Carbon Footprint

BACKGROUND- WHAT IS A CARBON FOOTPRINT? WHY SHOULD STUDENTS CARE?

The lead in lesson and material is up to the teacher to identify as part of the background science lesson. The intent of this lesson is to provide students lessons to develop number sense, computational skill, dimensional analysis, and representation of data. Instruction on the meaning of the units and how the conversion values are found and used should be included.

Standards:
Science –
Grades 5-7
KS Standard 6: Science in personal and environmental perspectives – The student will apply process skills to explore and develop an understanding of issues of personal health, population, resources and environment, and natural hazards

- Benchmark 2: The student will understand the impact of human activity on resources and the environment

KS Standard 7: History and Nature of Science – The student will examine and develop an understanding of science as a historical human endeavor

- Benchmark 1: The student will develop scientific habits of mind

Grades 8-12
KS Standard: Science in personal and environmental perspectives - The student will develop an understanding of personal and community health, population growth , natural resources, environmental quality , natural and human-induced hazards, science and technology in local, national, and global settings

- Benchmark 3 The student will understand that human populations use natural resources and influence environmental quality
- Benchmark 4 The student will understand the effect of natural and human-influenced hazards

Mathematics
Grade 6 - 8
Standard 1: Number and Computation – The student uses numerical and computational concepts and procedures in a variety of situations

- Benchmark 1: Number Sense - The student demonstrates number sense for rational numbers and simple algebraic expressions in one variable in a variety of situations
- Benchmark 3: Estimation – The student uses computational estimation with rational numbers and the irrational number pi in a variety of situations
- Benchmark 4: Computation – The student models, performs , and explains computation with positive rational numbers and integers in a variety of situation

Standard 3: Geometry – The student uses geometric concepts and procedures in a variety of situations

- Benchmark 2: Measurement and Estimation – The student estimates, measures, and uses measurement formulas in a variety of situations

Prep:

*Each student will need to bring an electric bill and a gas bill from home, preferably bills over the same month.

*Each student will need to find out how many gallons of gasoline their family used last month.
*Get a sample bill from the utility company (or bring your own), enlarge onto a transparency and highlight the relevant portions. Or, scan the bill into your computer, highlight the relevant parts and project so the entire class can see.

1. **Home electricity/gas/wood use for one month:**
   a. Electricity:

$$[\_\_\_\_\_\_\_\_\ kWh] \times \left[\frac{0.863\ kg\ CO_2}{kWh}\right] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

   b. Natural gas:

$$[\_\_\_\_\_\_\_\_\ cubic\ feet] \times \left[\frac{0.0538\ kg\ CO_2}{cubic\ foot}\right] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

   c. Wood:

$$[\_\_\_\_\_\_\_\_\ pounds\ of\ wood] \times \left[\frac{0.434\ kg}{pound}\right] \times \left[\frac{0.6948\ kg\ CO_2}{1\ kg\ wood\ burned}\right] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

> 1. Total CO_2 from home electricity/gas/wood use:
> ___________ kg CO_2

2. **Transportation:**
   a. Car:

$$\_\_\_\_\_\_\_\_\ gallons\ of\ gas\ per\ month \times \left[\frac{8.702\ kg\ CO_2}{gallon\ of\ gas}\right] + [number\ of\ passengers] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

   b. Bus:

$$\_\_\_\_\_\_\_\_\ miles\ of\ bus\ travel + \left[\frac{6\ miles}{gallon\ of\ diesel}\right] \times \left[\frac{9.955\ kg\ CO_2}{gallon\ of\ diesel}\right] + [number\ of\ passengers] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

   c. Planes:

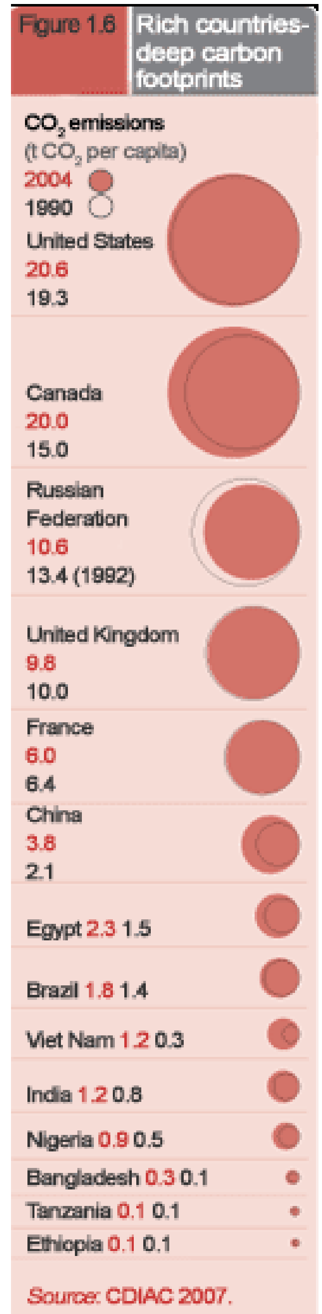
$$\_\_\_\_\_\_\_\_\ miles\ of\ air\ travel\ in\ one\ month \times \left[\frac{0.725\ kg\ CO_2}{mile}\right] = \_\_\_\_\_\_\_\_\ kg\ CO_2$$

> 2. Total CO_2 from transportation:
> ___________ kg CO_2

Total CO_2 footprint: ________________

Extensions

1. Have students compare their footprint with the US average and with the per capita figures from other countries. (Vocab: “per capita”) (Figure shows tons of CO_2 per capita for the years 1990 and 2004 for various countries.) http://hdr.undp.org/en/statistics/data/climatechange/footprints/



2. Have students access http://science.howstuffworks.com/global-warming.htm to learn how CO_2 affects the greenhouse effect.

3. Have students use the online carbon footprint calculator at http://www.zerofootprintkids.com/kids_home.aspx and compare their results to what they calculated on the front page. How are they the same? How are they different? Why is their footprint so different than somebody’s from India or China?

Additional Sources: Carbon Footprint

Understand what a carbon footprint is at: http://www.carbonfootprint.com/carbonfootprint.html
Calculate your carbon footprint at: http://www.nature.org/initiatives/climatechange/calculator/
Calculate household emissions at: http://www.epa.gov/climatechange/emissions/ind_calculator.html

APPENDIX B Fermi Questions

Fermi Question
A lesson on number sense and estimation (see http://www.aactm.org/documents/08_fall/activities-Problems/fermi_question-MTMS.pdf an article that I wrote on using Fermi Questions). The article describes a method for using Fermi Questions as part of lesson including introducing and leading students through the estimation process and calculations.
Standards:
Science: Grades 5-7
KS Standard 6: Science in personal and environmental perspectives – The student will apply process skills to explore and develop an understanding of issues of personal health, population, resources and environment, and natural hazards

- Benchmark 2: The student will understand the impact of human activity on resources and the environment

KS Standard 7: History and Nature of Science – The student will examine and develop an understanding of science as a historical human endeavor

- Benchmark 1: The student will develop scientific habits of mind

Science: Grades 8-12
KS Standard: Science in personal and environmental perspectives - The student will develop an understanding of personal and community health, population growth , natural resources, environmental quality , natural and human-induced hazards, science and technology in local, national, and global settings

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Mathematics
Grade 6 - 8
Standard 1: Number and Computation – The student uses numerical and computational concepts and procedures in a variety of situations

- Benchmark 1: Number Sense - The student demonstrates number sense for rational numbers and simple algebraic expressions in one variable in a variety of situations
- Benchmark 3: Estimation – The student uses computational estimation with rational numbers and the irrational number pi in a variety of situations
- Benchmark 4: Computation – The student models, performs , and explains computation with positive rational numbers and integers in a variety of situation

Standard 3: Geometry – The student uses geometric concepts and procedures in a variety of situations

- Benchmark 2: Measurement and Estimation – The student estimates, measures, and uses measurement formulas in a variety of situations

Purpose:
Develop students' sense of scale on items related to the greenhouse effect
Develop students' ability to estimate
Develop research skills to determine values

Practice on dimensional analysis

1. How much money would be saved on fossil fuels if everyone in your class (a) rode their bikes or (b) carpooled for one month?

Bike: (number of people in your class) / (average miles per month in car) x (average fuel efficiency, mpg) x (price per gallon of gasoline) OR (number of people) x (number of gallons of gasoline used in one month) x (price per gallon of gasoline)

Sample: $20 \text{ people per class} \times \frac{1000 \text{ miles}}{\text{month}} \div \frac{20 \text{ miles}}{1 \text{ gallon}} \times \frac{\$2.50}{\text{gallon}} = \$2500 \text{ per month}$

Carpooling: (answer from Bike question) / (number of people per car)

Sample: $\frac{\$2500}{\text{month}} \div \frac{4 \text{ people}}{\text{car}} = \$625 \text{ saved per class per month}$

2. How much water would it take to produce enough ethanol to fuel all of the vehicles in our state for one month? (Three to four gallons of water are required to produce one gallon of ethanol)
Ref: http://www.ksda.gov/includes/document_center/renewable_energy/Fueled%20by%20Farmers/ProducingBiofuelsinKansas.pdf

(Number of vehicles in Kansas) x (average miles driven per month) / (average fuel efficiency, mpg) x (10% (.10) ethanol/gasoline blend) x (4 gallons water per gallon of ethanol)

Sample:

$100\,000 \text{ vehicles in Kansas} \times \frac{1000 \text{ miles}}{\text{month}} \div \frac{20 \text{ miles}}{\text{gallon}} \times \frac{10 \text{ parts ethanol}}{100 \text{ parts gasohol}} \times \frac{4 \text{ gallons water}}{1 \text{ gallon ethanol}} = 2{,}000{,}000 \text{ gal } H2O \text{ per month}$

3. If all the countries in the world used energy at the same rate as the U.S., how long would our world's fossil fuels last? *crc.nv.gov/docs/world%20fossil%20reserves.pdf, http://en.wikipedia.org/wiki/World_energy_resources_and_consumption#Fossil_fuel*

Sample:

$300 \times 10^{21} \text{ J in reserve} \times \frac{1 \text{ person in U.S.}}{11.4 \text{ kW} = 11.4 \times 10^{3} \text{ J per second}} \times \frac{1 \text{ year}}{32 \times 10^{6} \text{ seconds}} \times \frac{\text{world population}}{6.0 \times 10^{9} \text{ people}} = 137 \text{ years}$

4. Estimate the mass of lead deposited each year in London due to emissions from automobiles. Each liter of gas contains about 2 grams of lead.

(Number of cars in London) x (average number of liters used per year) x (2 grams lead emitted per liter)

(from http://www.inference.phy.cam.ac.uk/withouthotair/c13/page_76.shtml , "Sustainable Energy - Without the Hot Air," David J.C. MacKay)

5. I love milk. If I drinka-pinta-milka-day, what energy does that require?

A typical dairy cow produces 16 litres of milk per day. So my one pint per day (half a litre per day) requires that I employ 1⁄32 of a cow. Oh, hang on – I love cheese too. And to make 1 kg of Irish Cheddar takes about 9 kg of milk. So consuming 50 g of cheese per day requires the production of an extra 450 g of milk. OK: my milk and cheese habit requires that I employ 1⁄16 of a cow. And how much power does it take to run a cow? Well, if a cow weighing 450 kg has similar energy requirements per kilogram to a human (whose 65 kg burns 3 kWh per day) then the cow must be using about 21 kWh/d. Does this extrapolation from human to cow make you uneasy? Let's check these numbers: www.dairyaustralia.com.au says that a suckling cow of weight 450 kg needs 85 MJ/d, which is 24 kWh/d. Great, our guess wasn't far off! So my 1⁄16 share of a cow has an energy consumption of about 1.5 kWh per day. This figure ignores other energy costs involved in persuading the cow to make milk and the milk to turn to cheese, and of getting the milk and cheese to travel from her to me.

(from http://www.inference.phy.cam.ac.uk/withouthotair/c13/page_76.shtml , "Sustainable Energy - Without the Hot Air," David J.C. MacKay)

References:

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APPENDIX C Graphing: Interpretation

Graphing: Interpretation

The intent of this lesson is to review graph interpretation. Understanding many of the graphs presented to explain and project the effects of climate change and global warming requires skill in looking at data represented in a variety of graphical and tabular means. Often we assume students have the skill and experience to interpret these, but this is not a safe assumption as the data representation is often distorted to "cherry-pick" or overstate a small difference.

The lesson can be used at different points, in whole or in part, when teaching about the topics of climate change and global warming.

Standards:

Grades 5-7

KS Standard 6: Science in personal and environmental perspectives – The student will apply process skills to explore and develop an understanding of issues of personal health, population, resources and environment, and natural hazards

- Benchmark 2: The student will understand the impact of human activity on resources and the environment

KS Standard 7: History and Nature of Science – The student will examine and develop an understanding of science as a historical human endeavor

- Benchmark 1: The student will develop scientific habits of mind

Grades 8-12

KS Standard: Science in personal and environmental perspectives - The student will develop an understanding of personal and community health, population growth , natural resources, environmental quality , natural and human-induced hazards, science and technology in local, national, and global settings

- Benchmark 3 The student will understand that human populations use natural resources and influence environmental quality
- Benchmark 4 The student will understand the effect of natural and human-influenced hazards

Mathematics

Grade 6 - 8

Standard 1: Number and Computation – The student uses numerical and computational concepts and procedures in a variety of situations

- Benchmark 1: Number Sense - The student demonstrates number sense for rational numbers and simple algebraic expressions in one variable in a variety of situations

Standard 2: Algebra – The student uses algebraic concepts and procedures in a variety of situations

- Benchmark 1: Patterns – The student recognizes, describes, extends, develops, and explains the general rule of a pattern in a variety of situations
- Benchmark 3: Functions – The student recognizes, describes, and analyzes linear relationships in a variety of situations

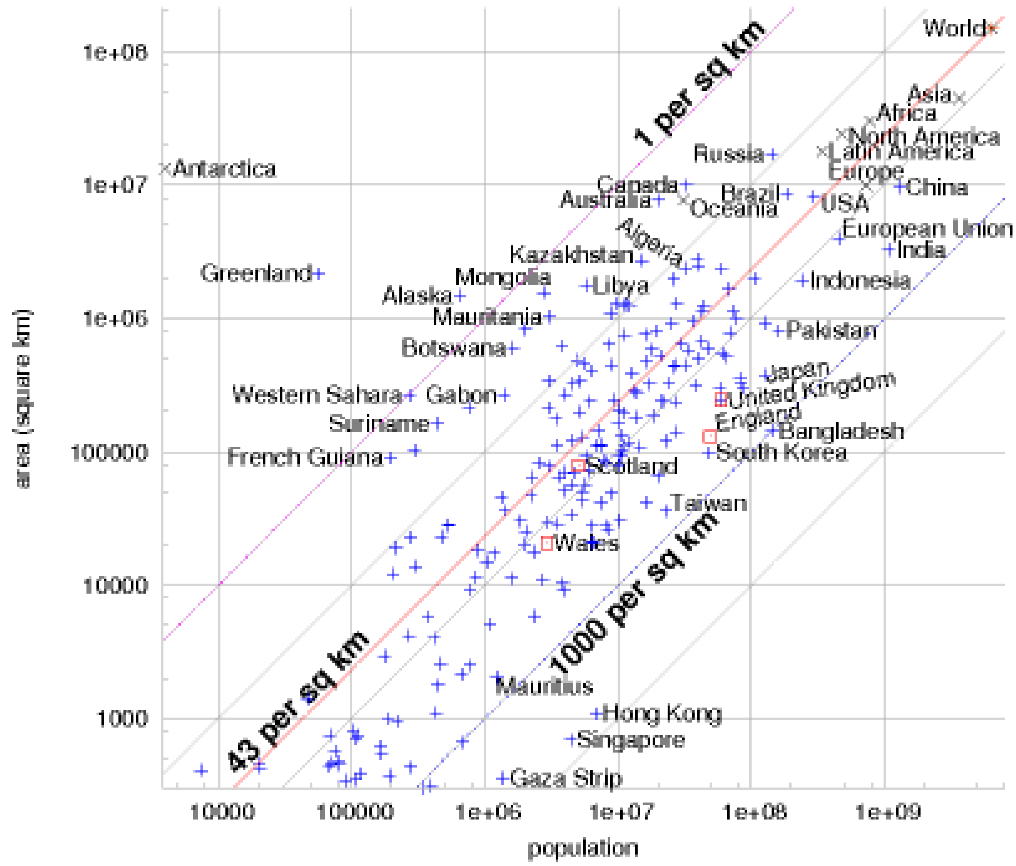
Standard 3: Geometry – The student uses geometric concepts and procedures in a variety of situations

- Benchmark 2: Measurement and Estimation – The student estimates, measures, and uses measurement formulas in a variety of situations

Standard 4: Data – The student uses concepts and procedures of data analysis in a variety of situations

- Benchmark 2: Statistics – The student collects, organizes, displays, and explains numerical (rational numbers) and non-numerical data sets in a variety of situations with a special emphasis on measures of central tendency

Part A



Source: David
“Sustainable
the hot air” p.

JC MacKay,
Energy – without
338

http://www.inference.phy.cam.ac.uk/withouthotair/cJ/page_338.shtml

1. What quantity is graphed on the x-axis?

2. What quantity is graphed on the y-axis?

3. The x-axis is labeled at 10,000 then 100,000 then 1,000,000 then 10,000,000. Does each square on the x-axis represent the same amount?
4. The y-axis is labeled 1000 then 10000, etc. Does each square on the y-axis represent the same amount?

5. What do the diagonal lines show?

6. What does the term “population density” mean?

7. What does this graph have to do with population density?

8. Which area of the graph shows a higher population density?

9. Which area of the graph shows a lower population density?

Source: David JC MacKay, “Sustainable Energy – without the hot air” p. 231 http://www.inference.phy.cam.ac.uk/withouthotair/c30/page_231.shtml

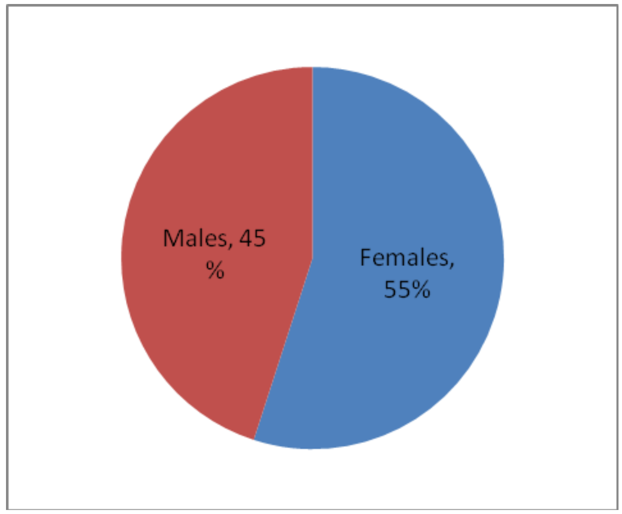
1. What does the acronym “GDP” represent? What is it used to measure?
2. What does the term “per capita” mean?
3. What is represented on the x-axis?
4. Is the x-axis linear or logarithmic? How can you tell?
5. What is represented on the y-axis?
6. What does (kWh/d/p) mean?
7. List 5 countries with a high GDP per capita and a high power consumption.
8. List 5 countries with a low GDP per capita and a low power consumption.
9. How can you use the GDP per capita and the power consumption to tell if a country is using energy efficiently?
10. List 5 countries that seem to be using energy the **most efficiently**.

11. List 5 countries that seem to be the **most inefficient.**

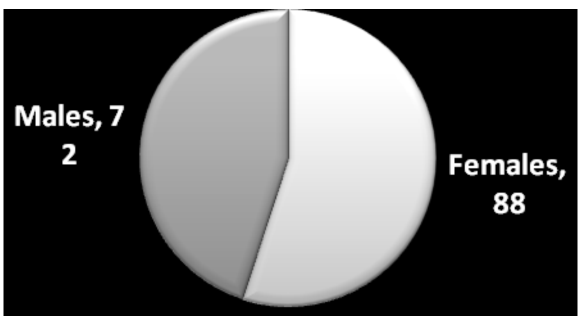
Graphing: Construction

1. Circle graphs

Circle graphs – “pie charts” – are used to show how quantities are distributed. For instance, a circle graph comparing the percentage of males to females at your school might look like this:



If you’re trying to show the number of females compared to the number of males, this is how your graph might look:

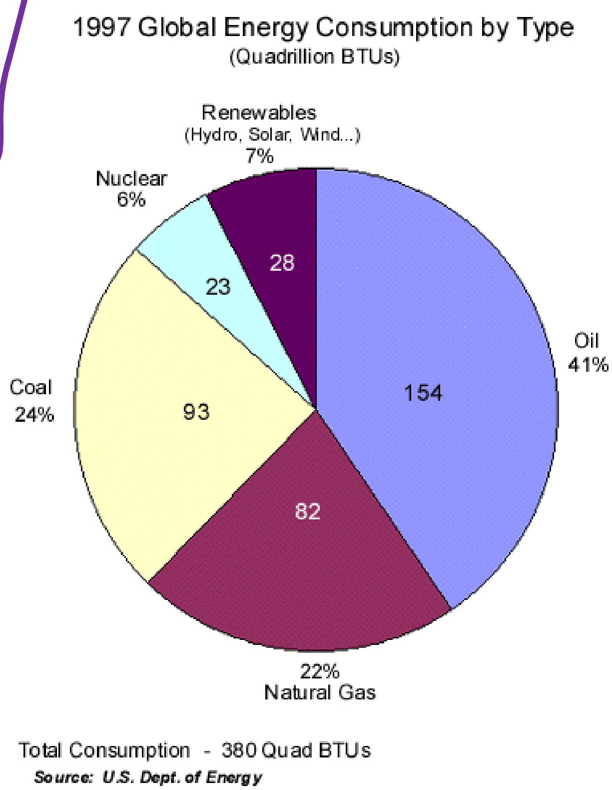


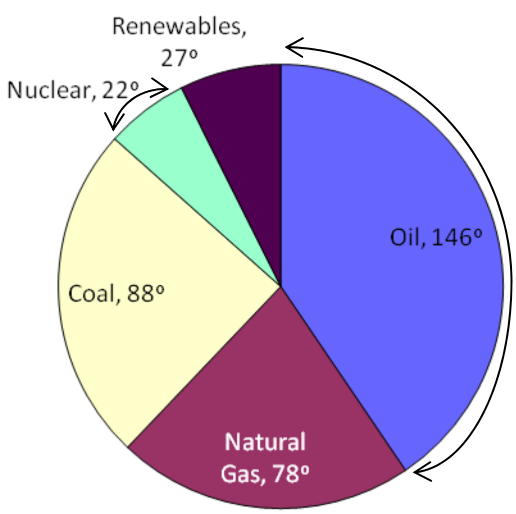
To make a circle graph, you just have to follow a few basic steps:

1. Get your data into a table

1997 Global Energy Consumption by Type (Quadrillion BTUs)		By degrees	*(Answers)*
Oil	154	= 154/380*360°	*146°*
Natural Gas	82		*78°*
Coal	93		*88°*
Nuclear	23		*22°*
Renewables	28		*27°*
Total	**380**		*360°*

2. Figure out how much of a circle each part of the data will occupy;
   a. **Find the total.**
   b. Divide the data by the total
   c. **Multiply by 360°**. (Why by 360°? Why not by 500° or some other number?)
3. Measure out and sketch your graph using a protractor and a pencil.





1997 Global Energy Consumption by Type

4. Erase the degree labels and replace with the actual values as shown in the chart on the right.

Making Line graphs

Line graphs are the way to display data that changes through time. You're going to use Excel to do this because there are hundreds of data points to display.

1. Copy and paste the table below into Excel.
2. Follow your teacher's instructions to graph the CO_2 in ppm for each month from 1958 through 2009. This data is from Mauna Loa, HI.

The "average" column contains the monthly mean CO_2 mole fraction determined from daily averages. The mole fraction of CO_2, expressed as parts per million (ppm) is the number of molecules of CO_2 in every one million molecules of dried air (water vapor removed).

From ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_mlo.txt

Year	Month	Decimal date	average CO2
1958	3	1958.208	315.71
1958	4	1958.292	317.45
1958	5	1958.375	317.5
1958	7	1958.542	315.86
1958	8	1958.625	314.93
1958	9	1958.708	313.2
1958	11	1958.875	313.33
1958	12	1958.958	314.67
1959	1	1959.042	315.62
1959	2	1959.125	316.38
1959	3	1959.208	316.71
1959	4	1959.292	317.72
1959	5	1959.375	318.29
1959	6	1959.458	318.16
1959	7	1959.542	316.55
1959	8	1959.625	314.8
1959	9	1959.708	313.84
1959	10	1959.792	313.26
1959	11	1959.875	314.8
1959	12	1959.958	315.59
1960	1	1960.042	316.43
1960	2	1960.125	316.97
1960	3	1960.208	317.58
1960	4	1960.292	319.02
1960	5	1960.375	320.02
1960	6	1960.458	319.59
1960	7	1960.542	318.18
1960	8	1960.625	315.91

1960	9	1960.708	314.16
1960	10	1960.792	313.83
1960	11	1960.875	315
1960	12	1960.958	316.19
1961	1	1961.042	316.93
1961	2	1961.125	317.7
1961	3	1961.208	318.54
1961	4	1961.292	319.48
1961	5	1961.375	320.58
1961	6	1961.458	319.77
1961	7	1961.542	318.58
1961	8	1961.625	316.79
1961	9	1961.708	314.8
1961	10	1961.792	315.38
1961	11	1961.875	316.1
1961	12	1961.958	317.01
1962	1	1962.042	317.94
1962	2	1962.125	318.55
1962	3	1962.208	319.68
1962	4	1962.292	320.63
1962	5	1962.375	321.01
1962	6	1962.458	320.55
1962	7	1962.542	319.58
1962	8	1962.625	317.4
1962	9	1962.708	316.26
1962	10	1962.792	315.42
1962	11	1962.875	316.69
1962	12	1962.958	317.7
1963	1	1963.042	318.74
1963	2	1963.125	319.08
1963	3	1963.208	319.86
1963	4	1963.292	321.39
1963	5	1963.375	322.24
1963	6	1963.458	321.47
1963	7	1963.542	319.74
1963	8	1963.625	317.77
1963	9	1963.708	316.21
1963	10	1963.792	315.99
1963	11	1963.875	317.12
1963	12	1963.958	318.31
1964	1	1964.042	319.57

1964	5	1964.375	322.24
1964	6	1964.458	321.89
1964	7	1964.542	320.44
1964	8	1964.625	318.7
1964	9	1964.708	316.7
1964	10	1964.792	316.79
1964	11	1964.875	317.79
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1966	6	1966.458	323.75
1966	7	1966.542	322.4
1966	8	1966.625	320.37
1966	9	1966.708	318.64
1966	10	1966.792	318.1
1966	11	1966.875	319.78
1966	12	1966.958	321.08
1967	1	1967.042	322.06
1967	2	1967.125	322.5
1967	3	1967.208	323.04
1967	4	1967.292	324.42
1967	5	1967.375	325
1967	6	1967.458	324.09
1967	7	1967.542	322.55
1967	8	1967.625	320.92
1967	9	1967.708	319.31

1967	10	1967.792	319.31
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1968	1	1968.042	322.57
1968	2	1968.125	323.15
1968	3	1968.208	323.89
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1968	5	1968.375	325.57
1968	6	1968.458	325.36
1968	7	1968.542	324.14
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1972	5	1972.375	330.07
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1973	3	1973.208	330.3
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1973	6	1973.458	332.07
1973	7	1973.542	330.87
1973	8	1973.625	329.31
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1973	10	1973.792	327.18
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1974	5	1974.375	333.15
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1974	7	1974.542	330.99

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1974	9	1974.708	327.41
1974	10	1974.792	327.21
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1974	12	1974.958	329.5
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1976	6	1976.458	334.05
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1977	9	1977.708	331.19
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1977	11	1977.875	332.35
1977	12	1977.958	333.47

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1988	11	1988.875	349.99
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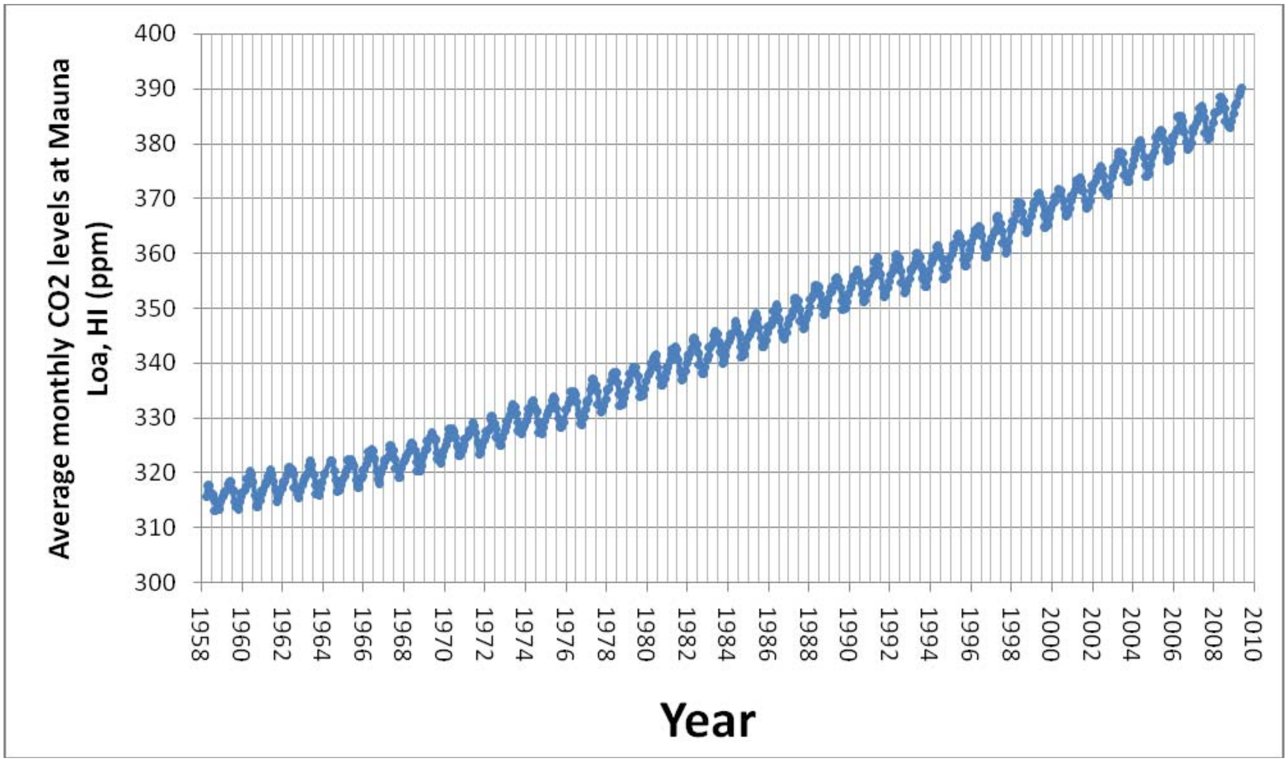
2009	5	2009.375	390.18


Average monthly CO2 levels at Mauna Loa, HI (ppm)
400
390
380
370
360
350
340
330
320
310
300
1958
1960
1962
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STEM Symposium Collaborative Pilot Study
Middle School Science Teachers Readiness for Math Infusion

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Background
For mathematics infusion into middle school science classes to be effective in improving students' mathematics and science proficiency, it is imperative first that science teachers involved have a deep understanding of the mathematics to be infused. In most states, students must demonstrate proficiency in basic mathematics before they start the professional phase of their undergraduate education. In addition, most states also require that middle school science teachers have a degree in a science discipline. At most universities, science degrees include some college-level math, often up to calculus. Even though we can assume that they have passed a basic math proficiency test and completed college-level mathematics courses, it is possible that science teachers will enter the profession without the deep understanding of mathematics required, first of all, to recognize opportunities to use the mathematical basis of science to enrich science lessons or, secondly, to teach math as a part of a science lesson. This is particularly true if teachers have learned math by a memorizing formulas and learning how to plug in numbers to arrive at correct answers. The lack of a true understanding of simple math concepts becomes obvious when undergraduate science students, including students planning careers as teachers, are asked to apply simple math processes in an undergraduate science classroom or laboratory.

Several examples illustrate the problem.

- Undergraduate science students often have difficulty determining how to make a given volume of a solution at certain concentration from a stock solution of a greater concentration until they are given a formula.
- When asked to graph data students often connect data points and create line graphs when regression lines are appropriate.
- After plotting data and generating a regression line using a computer program, students often are unable to use the equation for the line to determine a point on the line.
- Many students have difficulty applying probability concepts to simple genetics problems.

In all of these examples, if the students are given the formula or told how to "plug" numbers into an equation they can complete the operation successfully. Because most proficiency tests require only the ability to perform math operations, these students can typically pass a test of basic math proficiency. If these students become teachers it is unlikely that they will be able to find opportunities to reinforce math during a science lesson or effectively teach the math that underlies their science.

This project proposal starts with the assumption that we do not really know how well middle school science teachers understand mathematics. The above examples are taken from the general population of undergraduate science majors in introductory courses. We do not know if students with these weaknesses in applied math become science teachers. It is important to know what teachers know and are able to do before beginning professional development programs to facilitate the infusion of math into middle school science classes. Therefore, the initial phase of the work proposed is exploratory. We plan to test the practical math proficiency of a sample of pre-service middle school science teachers using examples from middle school science lessons. We then plan to provide specific instruction that aims to help these pre-service teachers recognize opportunities for math infusion and to apply math concepts to middle school science lessons. We will use exemplary math curricula (such as *Connected Math*) to demonstrate the mathematical basis of middle school science concepts. After instruction we will again test the practical math proficiency of the students. We hypothesize that this specific instruction will improve pre-service science teachers applied math proficiency and thereby their ability to teach math-infused science.

Research Questions

1. Are pre-service middle school science teachers able to recognize opportunities to apply middle school mathematics concepts to middle school science lessons?
2. Are pre-service middle school science teachers able to explain math applications used in middle school science lessons?
3. Does specific instruction in the infusion of math into middle school science improve the applied math proficiency of pre-service middle school science teachers?

Project Plan

This project will be carried out jointly by Beverly Clendening, Ph.D., Hofstra University, Department of Biology and Theodora Pinou, Ph.D. Western Connecticut University, Department of Biological and Environmental Sciences.

<u>Preliminary Phase: Fall 2009</u>

Math Proficiency Test. This project assumes that the pre-service teachers we will be working with are proficient in middle school math operations. We will first test this assumption by administering a mathematics proficiency test. We will develop a proficiency test to assess proficiency in middle school level mathematical operations, using specific items from a math placement test developed and used extensively by the Mathematics Department at Hofstra University.

Applied Math Proficiency Test. We will develop a set of abbreviated middle school science lessons that are amenable to math infusion but from which the math has been omitted. These will be used as the pre- and post-test of applied math proficiency. We will also develop rubrics for scoring the students' responses to this test.

Materials for Instruction in Math Infusion. The math infusion enrichment program will be developed using materials adapted from Connected Math, AIMS, GEMS projects as will as resources available through ERIC.

Pre-Tests: January - February 2010

Dr. Pinou will administer both proficiency tests to pre-service science teachers (15) who are enrolled in her Science Methods class at Western Connecticut University. Individual and group results will be compiled and the major weakness in operational and applied math proficiency will be identified. As a part of the analysis, we will examine data from biology education, chemistry education and physics education students separately to determine if there is a difference between the disciplines.

Instruction: Spring 2010

A voluntary, pre-service enrichment program will be offered (2 Saturdays – 10 hours total enrichment). Volunteers (12 students) will be paid $150 for the two sessions only with completion of both sessions and a post-test.

Session 1: Model lessons aligned to state curriculum will be used to demonstrate how mathematics can be incorporated into middle school science lessons. Students will also be introduced to the AIMS and GEMS program materials and other web-based resources including ERIC

Examples of model lesions:

1. Properties of Light
   Science content: Light travels in a straight line until it is reflected, refracted or absorbed.
   Math content: Geometry. Concepts of appoint, line, line segment, ray, intersecting lines, parallel lines, angles, symmetry.
   Model Lesson: *Ray's Reflection*. AIMS Education Foundation
2. Solar System
   Science content: Size of sun and planets, distance between planets, distance and apparent size, rotation of earth, revolution of earth around the sun
   Math content: proportional reasoning (scales and ratios), estimation, measurement, calculation, geometry, graphing.
   Model Lesson: *Out of this world*. AIMS Education Foundation
3. Density
   Science content: density, mass, volume, buoyancy
   Math Content: measurement (mass and volume), calculation (volume), ratios and proportion, equality/inequality, percentages, graphing.
   Model lesson: *Floaters and Sinkers*. AIMS Education Foundation

Session 2: Students will work in 3 groups of 4 students to develop their own math-infused lessons. Each group will share their work with the other groups at the end of the session. We will also edit the group work and share the materials with the Hofstra MSTP Project.

Post-testing: May 2010

The applied math proficiency test will be re-administered to Dr. Pinou's pre-service science teachers using different abbreviated science lessons.

Analysis

1. Research Questions 1: Are pre-service middle school science teachers able to recognize opportunities to apply middle school mathematics concepts to middle school science lessons? The results of the analysis of the applied math proficiency pre-test will provide an answer to this question for this limited population. The results of this pre-test will also serve as an indicator of the usefulness of this test on a larger scale.
2. Research Questions 2: Are pre-service middle school science teachers able to explain math applications used in middle school science lessons? We will informally evaluate this for the limited population of students who volunteer for the instruction phase. This portion of the project is intended to assess the need for more explicit math teaching instruction for science teachers.
3. Research Question 3: Does specific instruction in the infusion of math into middle school science improve the applied math proficiency of pre-service middle school science teachers? This question will be assessed by comparing the changes in pre-test and post-test scores of participants vs. non-participants on the applied math proficiency post-test.

Extensions:

1. The study could be repeated with current middle school teachers and could include study of gains in math proficiency of students. Quantitative analysis would require control and experimental groups or access to archived test scores from previous years.

2. Student volunteers in this study could be followed to see if they include math in science lessons more frequently than typical middle school teachers.

Budget

$150 stipend for 12 student participants	$1800
Materials and supplies	120
Lunch and refreshments for volunteers for two Saturdays ($15/person/day)	360
Travel between Long Island and Connecticut for BC (~50 miles one-way; 4 trips: 2 planning meeting, 2 workshop days; @ GSA rate $0.55/mile)	220
	$ 2500

Connecting Mathematics and Engineering
Engineering is Elementary Exploratory Project
Christine M. Cunningham, Ph.D. & the EiE team
June 29, 2009

The Engineering is Elementary (EiE) project has just begun to explore how to more explicitly draw out the mathematics connections that abound in our engineering activities. Currently, the lessons and activities as written have numerous possibilities for linking the mathematics that the children are studying at the time with the engineering challenges. Teachers have asked for lesson plans that articulate the mathematical connections. We have just begun to craft these connecting lessons. This project provided a first glimpse into the thinking of students and teachers about the relationship between mathematics and EiE/engineering. We were interested in understanding more about:
(a) whether elementary teachers using EiE materials are currently seeing the mathematics in the lessons
(b) if they do see the mathematical connections, the degree to which they were drawing these out for their students.
(c) whether students are making any connections between the engineering (and science) they are doing and mathematics
(d) whether children's associations with mathematics is related to what the teacher indicated she was teaching.

This exploratory pilot study was the first that explicitly looked at EiE and mathematics. During the 2008-09 school year, two EiE units were undergoing national field testing in five states, *Now You're Cooking: Designing a Solar Oven* and *A Long Way Down: Designing a Parachute.* These units have a strong mathematical base. Our study asked field test teachers to identify mathematical concepts they saw as interconnecting to the unit(s) they taught and also whether they structured instruction to help their students see these math connection explicitly. It also surveyed the children in the classes directly to better understand whether the students are able to discern the mathematics in the work that they were doing.

The data were gathered as part of a larger set of EiE post-assessments that are administered to the children and the teachers. A survey mailed to teachers (see Appendix A) asked:

- What mathematics topics their students were concurrently studying as part of their mathematics curriculum.
- Whether they spent extra time on the mathematics topics that were relevant to the engineering content.
- Whether they made explicit connections between teaching of ANY mathematics concepts and the EiE unit.
- Whether students noticed the connections between mathematics and engineering, and, if so, how they responded.

As part of a larger assessment of their knowledge and perceptions, students were asked:

- When you were designing your [parachute/solar oven] did you use any math? (yes/no)
- If yes, what kind of math did you use?
- How did math help you to design a [parachute/solar oven]?

It's a Long Way Down ~~ Aerospace Engineering: Designing Parachutes

The *It's a Long Way Down* unit connects with the science of astronomy and the solar system. The design challenge in this unit focused on designing parachutes. Students watch a demonstration that uses models to show how the thickness of an atmosphere affects how quickly or slowly objects fall through the atmosphere. Students then perform a controlled experiment examining how changes in a parachute's canopy material, canopy size, or suspension line length affect how quickly or slowly it falls. As a class, students analyze the data to determine the properties of a parachute that will slow a falling load the most. After students have developed some background knowledge they use the Engineering Design Process to design a parachute that meets certain specifications. They are introduced to two more "real life" criteria that must be addressed by their parachute designs: size limitations and a specific drop speed. Students then design and test their parachutes and analyze the results. Based on their analyses, students improve their designs.

Teacher Responses

Respondents to the Parachutes survey included 14 teachers who taught 31 classrooms. All the teachers taught grades 3-5. Of the 14 teachers, 3 of the teachers indicated that they were science specialists and therefore were not responsible for or clear about the mathematics that was being covered by the classroom teacher. Responses from these teachers included "*I am the Science resource teacher so I'm not sure*" and "*N/A I don't teach math*."

The remaining teachers' responses to the mathematics content they were studying suggest that all of them were covering topics in mathematics that could have been connected with the engineering unit. Four of these teachers indicated that they did indeed explicitly draw out the connections, a couple more "weren't sure." However, when asked whether the students noticed the connection between mathematics and engineering, of the 7 teachers who responded, all but one (who indicated she was departmentalized and taught only science not math) indicated that their students were making connections. Teachers stated:

> *"Yes, they were having ah ha moments."*
> *"Yes, Calculating formulas, measuring lines etc."*
> *"Yes, Most liked seeing a real use for math."*
> *"Yes, Assisting with predictions and importance of accuracy."*
> *"Yes, several students had "moment of clarity" moments related to diameter of a circle to diameter of their canopy."*
> *"Yes, They remembered and used the information without reteaching."*

Student Responses

Responses were garnered from 141 students who designed parachutes. Of these, 115 of the students (82%) indicated that they used math in designing their parachutes. 26 of the students responded they did not use math. An analysis of students' open-ended responses about what kind of math they used indicated that, overwhelmingly students identified measurement as the math they were using. 65% of students focused on measurement: *"You use measuring"* or *"The kinds* *of math I used were measurements.*" Sometimes students' specified that this entailed measuring the parts of the parachutes: "*We had to measure the suspension lines.*" Occasionally they mentioned measuring time as well: *"We measured the string. We measured time.*" And "*counting how many seconds it takes to land and measuring strings".*

After measurement, the second most commonly mentioned mathematical topic were the basic mathematical operations (addition, multiplication, division, and subtraction). 16 students (11%) mentioned performing these functions, sometimes in conjunction with measurement: "*The math of subtracting and adding", "I used addition when I measured the length of the suspension lines*."

A few students connected the mathematics to other topics that they had or were studying. These included mentions of basic geometry concepts including: area, perimeter, circumference, diameter, or radius and averages.

> *"Some math that you use are circumference, diameter, radius and pi (3.14) to figure the circumference of the parachute."*
> *"Degrees. The angle of everything affects the parachute."*
> *"We needed to use different sizes of strings. So we needed to measure the stings. And we averaged the scores."*

Students' responses to how math helped them to design a parachute again primarily focused on measurement. Over half of the students again responded that math helped them to measure a part of their parachute:

> *"We measured the length of the suspension lines. It helped us make them."*
> *"It helped me measure the different lengths of string and data."*

Some of the students were able to make the connection between making accurate measurements and the performance of the parachute in general terms such as "falling right" or "falling correctly":

> *"It gave us the right string lengths so the parachute would fall right."*
> *"Using math helped me design the parachute because I knew the exact measurements to make it fall correctly.*"
> *"It gave us a balanced parachute so all the strings were the same length."*

And a small number of the students articulated the relationship between measuring and building an optimal parachute. These students understood that the mathematical measurements that they were performing could assist them in understanding how to design a parachute that could meet the specifications outlined by the challenge. For example:

> *"It helped us find out what parachute is better and would work more effectively."*
> *"Certain sized canopies make your parachutes fall faster or slower."*
> *"By using math, we could make the parachutes fall for more or less time."*
> *"It help because if it went farther and a lot of time then we will try to make it go farther but in less amount of time. It show us if we need more or less air."*

In designing their parachutes, almost all students identified measurement as an area that intersected with mathematics. Many fewer students (and teachers) reached beyond this variable to connect the unit with mathematical concepts related to area—a critical concept in successfully creating a parachute. However, some children's responses indicate that they understood the connection implicitly. Their failure to articulate the link in their responses raises possibility of a disconnect between question of what children come to "know" about mathematical relationships through an experience and what they can then express in language.

Now You're Cooking ~~ Green Engineering: Designing Solar Ovens

The *Now You're Cooking* unit connects with science concepts related to energy. The design challenge in this unit focused on designing the insulation for a solar oven. Students first conduct a controlled experiment to determine how quickly or slowly different materials transfer heat energy (i.e. whether a material is a good thermal insulator or a good thermal conductor). They then assess the environmental impact of using each of these materials to insulate a solar oven design. Then students use the Engineering Design Process as they design, test, and improve their own solar ovens (made out of shoeboxes), focusing on the material(s) used to insulate the design. Students attempt to balance what they have learned about the insulative properties and environmental impacts of different materials in order to design solar ovens that are both functional and environmentally friendly.

<u>Teacher Responses</u>

Respondents to the Parachutes survey included 15 teachers who taught 31 classrooms. The teachers taught grades 3-5. Eight of the teachers indicated that they connected the engineering with mathematics they were teaching and three of the teachers indicated that they spent extra time on mathematics concepts that were relevant to the engineering in the unit. The most reinforced mathematics concept, according to the teachers, was temperature. Other concepts they covered included graphing, averages, positive and negative numbers, and measurement.

Again the teachers indicated that they were helping their students to see the connections between the mathematics and the engineering/science they were using. Teacher believed that there students were seeing the connections mentioning:

> *"Yes, I believe so. We briefly talk about how math is closely related to science whenever there needs to be some math work during our lab activities. This time, I just discussed how to total scores, asked if they had ever had negative numbers in math, and reminded them that we were once again bringing our math knowledge/abilities into our science world."*

> *"Yes, Many saw that math is a tool that all engineers need to use to help solve problems and many were excited to use their skills from another time of day for accuracy in Science class. It really hit home the scaffolding we are always trying instill in our lessons."*

> *"Yes, They recalled how we had done Averages in the past and picked it up pretty quick. Great connection. The EiE unit didn't ask for averages, but I asked the groups to figure it out so they could see how their design compared."*

<u>Student Responses</u>

Only one teacher returned one classroom of responses to the Solar Ovens assessment. This teacher had focused on measurement and operations and the students' responses indicate that they made this connection to math. All but one of the 19 students indicated s/he had used math to design his/her solar oven. The students mentioned measuring, temperatures, and addition and subtraction as aspects of math that they used. Similar to the responses for parachutes, students indicated that using math helped them to make accurate measurements that improved the quality of their designs. They also mentioned the math calculations that the design challenge asked them to perform to determine their "scores" (for environmental impact, time, heat)—a form of assessment of their design.

Discussion

This first glimpse into student and teacher thinking about mathematics and engineering suggests that students (and teachers) are making connections between some of the mathematics concepts that they have learned and their use in an engineering project. In some cases, the students are able to articulate how using mathematics, particularly precise measurements, can help to create a better or more effective design. In their responses teachers stated that students were connecting mathematics to real-world problems.

However, the mathematical opportunities present in these two units are much deeper than those generally identified or explored by teachers. For example, the parachutes design challenge offered the chance for students to connect surface area, volume, and the geometry of circles in ways that few teachers, if any, teachers seem to have reinforced. In solar ovens graphs, averages, and temperature curves could be used.

One challenge that surfaced is that science in many schools is taught by a science specialist who, seemingly, is not in touch with the mathematics that is being taught by another teacher. This is problematic as chances to reinforce and connect what are being in learned in math class are not capitalized upon. Clearly to connect math and science if instruction is occurring by two separate teachers communication between the educators must occur!

A second challenge is that EiE units can be taught to a wide range of students across a number of grades; mathematical concepts may or may not be covered by that teacher or in that grade level. Future research will help to identify how to bolster the connections so they not only reinforce general mathematical concepts like measurement and simple operations but also can help students to apply more complex understandings about geometry and rates.

Overall, the ability of the majority of the children in the study to connect mathematics to their engineering challenges and their indication that it helped them to design a technology is promising. As we look to more closely integrate STEM in children's learning we hope to expand these areas of intersection.

Engineering is Elementary

Science & Math Curriculum Questionnaire

It's a Long Way Down: Designing Parachutes

In this questionnaire, we ask about the science and math you taught your students that is related to the EiE curriculum. Please answer the questions below as **completely** as you can.

Your name:_____________________________________
School:_______________________________
I taught the *Designing Parachutes* unit to _____ classrooms of grade _____ students.

Teaching about the Solar System. Please describe your science teaching schedule for the **Solar System** below, including the curriculum materials and/or guides that you used to teach your students. If you designed any of the curriculum materials or used unpublished materials, please explain the topic.

(example: Class A: Jan 22 & Class B: Jan 23; GEMS "Messages from Space" Activity 3; approx.1 hour)

Date(s)	Curriculum Resource / Topic of Science Lesson	Time Spent

2. Because you were teaching the *Designing Parachutes* unit, did you spend **more, the same amount,** or **less** time teaching about the Solar System this year than you have in previous years? Please explain.

☐ **More time** ☐ **The same amount of time** ☐ **Less time**

3. Did you make explicit connections between your teaching of the Solar System and the *Designing Parachutes* unit? ☐ **Yes** ☐ **No** If yes, please explain:

Teaching Math. During the period when you were teaching the *Designing Parachutes* unit, what mathematics topics were your students concurrently studying as part of their mathematics curriculum?

5. While you were teaching the *Designing Parachutes* unit, did you draw out or spend extra time on mathematics topics that were relevant to the engineering content in the unit? ☐ **Yes** ☐ **No**
6. Did you make explicit connections between your teaching of **any** mathematics concepts and the *Designing Parachutes* unit? ☐ **Yes** ☐ **No**

7. *If you answered yes to either question 5 or 6 above*, please describe:

Date	Mathematics Connection / Mathematics Lesson Topic	Time Spent

8. *If you answered yes to either question 5 or 6 above*: Did your students notice the connection between mathematics and engineering? ☐ **Yes** ☐ **No** How did they respond?

Engineering is Elementary
Science & Math Curriculum Questionnaire
Now You're Cooking: Designing Solar Ovens

In this questionnaire, we ask about the science and math you taught your students that is related to the EiE curriculum. Please answer the questions below as **completely** as you can.

Your name:____________________________________
School:______________________________

I taught the *Designing Solar Ovens* unit to _____ classrooms of grade _____ students.

Teaching about Energy. Please describe your science teaching schedule for Energy below, including the curriculum materials and/or guides that you used to teach your students. If you designed any of the curriculum materials or used unpublished materials, please explain the topic.

(example: Class A: Jan 22 & Class B: Jan 23; FOSS "Solar Energy" Part 3; approx.1 hour)

Date(s)	Curriculum Resource / Topic of Science Lesson	Time Spent

2. Because you were teaching the *Designing Solar Ovens* unit, did you spend **more, the same amount,** or **less** time teaching about Energy this year than you have in previous years? Please explain.

☐ **More time** ☐ **The same amount of time** ☐ **Less time**

3. Did you make explicit connections between your teaching of Energy and the *Designing Solar Ovens* unit? ☐ **Yes** ☐ **No** If yes, please explain:

Teaching Math. During the period when you were teaching the *Designing Solar Ovens* unit, what mathematics topics were your students concurrently studying as part of their mathematics curriculum?

5. While you were teaching the *Designing Solar Ovens* unit, did you draw out or spend extra time on mathematics topics that were relevant to the engineering content in the unit? ☐ **Yes** ☐ **No**

6. Did you make explicit connections between your teaching of **any** mathematics concepts and the *Designing Solar Ovens* unit? ☐ **Yes** ☐ **No**

7. *If you answered yes to either question 5 or 6 above*, please describe:

Date	**Mathematics Connection / Mathematics Lesson Topic**	**Time Spent**

8. *If you answered yes to either question 5 or 6 above*: Did your students notice the connection between mathematics and engineering? ☐ **Yes** ☐ **No** How did they respond?

Preliminary proposal STEM Symposium

Authors: Linn and Dorsey

TITLE: STEM Learning Outcomes and the Practices of Educators (SLOPE)

The SLOPE project will investigate how the practices of educators impact student learning by linking high-stakes tests, embedded assessments, and teacher actions in a large-scale online instructional program. Far too little attention is paid to evidence in the classroom of effective and ineffective practices and curriculum materials. Cyber-infrastructure advances enable us to provide much more timely and detailed information to teachers while they are teaching, while they are preparing for the next class, and while they are refining their materials and practice for the next year. Cyber-infrastructure also enables us to study how variations in teacher practice impact student learning.

SLOPE will assess how activities of teachers lead to student learning gains. Teachers can use information such as individual progress on activities, social interactions, pre-tests and post-tests, embedded notes, and annual assessments to revise and improve instruction. Logged information will help teachers shape their practice and tailor the curriculum activities for their state, school, and students. We will study how this information can be used effectively. The project will identify ways that schools and states can use this information to improve teaching and learning. The project will use cutting-edge assessment technology, data-mining techniques, and online, technology-enhanced curriculum materials. SLOPE will study how teachers interact with curriculum and respond to students and investigate how variation in teacher practice can contribute to student learning. By linking SLOPE data to statewide data systems, the project will explore connections between the practices of educators and high-stakes outcome measures. SLOPE will connect continuous assessment at the individual, classroom, and student level with performance on statewide standardized tests. We will document relationships between in class performance, online performance, and high stakes outcome measures.

To gain an overview of how technology-based curriculum can affect teaching and learning, the SLOPE project will concentrate on the overall research question: How do teachers impact student learning gains? And how can schools and states use information about teacher impacts on learning to improve science courses?

To investigate this topic, SLOPE will study teacher practice, student learning, and high-stakes measures of student progress. The findings will inform design and use of statewide data systems. Research questions include:

Research Question 1: What do teachers do? What is the trajectory? What is sustained?

New technology-enhanced science curricula support continuous assessment of student learning as well as extensive new opportunities for teaching practice. Teachers can gather information about student progress by reviewing student work during class, from one class to the next, and from one year to the next. They can use this information to provide feedback to students, revise their lesson plans for a unit, or customize the instruction from one year to the next.

As this technology is integrated into the classroom, new questions begin to arise as to their effects on teaching practice. With a proliferation of real-time information available to teachers, questions arise such as when teachers review student work or how often they use the information to interact with the whole class, small groups or individuals. The opportunity to provide feedback to students easily and frequently also raises interesting questions: What kind of feedback do teachers provide? Do they use the feedback provided by the developers in the form of "pre-made" comments? Do they add their own comments? How many unique messages do they send? What sorts of changes in lesson plans do teachers implement during the implementation of a unit (allocation of time; addition/subtraction of homework; redesign of instruction)?

Technology also makes it possible for teachers to take ownership of the curriculum in a way not possible before. This raises unique questions about their interaction with curriculum. What sorts of changes arise from one year to the next? Do teachers customize the instruction? Do teachers change the order of topics in the curriculum?

What factors contribute to teachers practice? Do they attend workshops? Do they collaborate with another teacher at the school?

Research Question 2: How does variation in teacher practice contribute to student learning?

Once we have documented common teacher activities we will link these to student outcomes measured using embedded assessments administered individually. We will use data mining to determine overall relationships. In addition we will investigate three specific questions.

First, we will study feedback by (a) allowing teachers to select among pre-made comments; (b) comparing pre-made comments to comments designed by teachers; and (c) varying pre-made comments based on theoretical principles such as knowledge integration, desirable difficulties, and direct instruction. We will design pre-made based on student responses to the unit. We will offer workshops to teachers to support their efforts to create their own comments. We will study how teachers select comments by observing selected teachers as they respond to students.

Research Question 3: How would this data be used in a statewide data system?

As one example of such a potential implementation, we can consider the one-to-one computing initiative in the state of Maine. This initiative provides a uniform networked computing environment to over 36,000 students across the state. The existence of this network enables the SLOPE program to provide curriculum easily to many classrooms and sets the stage for straightforward deployment of ongoing assessment at a much finer detail than has ever before been possible. Curriculum can be tailored to address statewide standards and sequences as well as district- or school-based desires. All of this can be tailored and deployed easily.

The possibility of deploying such curriculum easily across many classrooms raises tantalizing possibilities for research, evaluation and teacher development. Teachers, schools and states can benefit from information about teachers' curricular decisions, teacher-student interactions and student performance, and aggregated data about areas of need can be placed directly in the hands of schools as well as statewide entities, allowing changes to occur in real time by those empowered to make the difference at the classroom level.

With such a statewide system in place, professional development can also address common training needs and benefit from the economy of scale such a system provides. Research and evaluation projects within the state can also benefit from the spin-off of such a system as the platform enables them to ask and answer fine-grained questions about student performance and teacher interaction and make comparisons between outside projects and the SLOPE curriculum.

Statewide data systems currently enable detailed analysis for state standardized testing results in STEM areas, from the state level down to individual student performance. By linking SLOPE implementation with such statewide data systems, performance on continuous assessments may be compared with performance on large-scale standardized tests. By employing data-mining technologies, the SLOPE system will also permit analysis of teacher and school use of curricula across a state and correlation with specific standardized testing results.

Research Question 4: Long term, what are valid measures of student progress? How do the embedded/continuous assessments compare to standardized state tests?

This research program has the long-term goal of improving instruction including the integration of all the STEM disciplines, strengthening student assessment, and increasing the effectiveness of teachers.

Embedded assessments can track progress in integration of mathematics, technology, and science. By designing embedded assessments that capture use of mathematics in science, technology and science, and use of science in mathematics we can link these accomplishments.

The embedded assessments allow for continuous assessment of students. The nature of this assessment needs clarification. By comparing SLOPE assessments to statewide tests we can improve overall assessment of student learning. This research program contributes to understanding of assessment of knowledge integration.

The project offers many opportunities for long-term assessment of teachers. By linking teacher activities to student learning we can begin the process of diagnosing how professional development contributes to student outcomes.

Resources and Prior Research

The project will build upon prior research and existing software solutions. The WISE group and the Concord Consortium have over 50 years of combined prior research on the advantages of computer-based resources in teaching and learning. Because of prior and ongoing work, we are in a unique position to combine authorable activities, research-based instructional resources, and embedded online assessments into a unified electronic environment. This allows us to create learning opportunities of unprecedented power, to vary the form and content of instruction systematically, to track in detail how individual students use these opportunities, and to create detailed performance assessments at the student, class, school and district level. This project will draw upon several past projects, including:

The Web Based Inquiry Science Environment (WISE) projects at UC Berkeley, developed and tested web-based science materials designed using a Knowledge Integration (KI) framework (Linn & Eylon, 2006; Slotta & Linn, 2000) to ensure in-depth student learning. This framework emphasized the central importance of engaging learners in guided inquiry through a broad range of experiences provided by a mix of technology and teacher interventions, which provide ample opportunities for students to integrate their observations and link them with prior knowledge. . WISE research demonstrated that well-planned, in-depth science teaching with technology enhanced projects created more knowledgeable students who were better equipped for life-long learning. VISUAL will add functionality to WISE to support authoring with visualizations, new assessments, and new supports to broaden the impact of science instruction.

The Modeling Across the Curriculum (MAC) project directed by Paul Horwitz at the Concord Consortium (CC) developed two multiple-week modeling activities for each year of the usual three-year high school science sequence in order to develop general modeling skill development. The project automatically logged actions from over 10,000 students as they explored models. Synthesizing these logs gave indicators of the systematicity of student exploration. The project reports that students' systematic use of models was correlated with content learning as measured by pre-to-post-test gains (Buckley & Gobert, 2005; Horwitz & Gobert, 2007; Buckley, Gobert, & Horwitz, 2006). SLOPE will refine and augment these logging tools.

The Technology Enhanced Learning of Science (TELS) Center, a collaboration under the direction of Marcia Linn and Bob Tinker that included six other univer-sities including North Carolina Central University, and seven school districts (ESI-0334199, 2003-2008, $10M).

TELS set out to increase the numbers of teachers whose students are learning crucial science concepts by using proven, technology-enhanced secondary science curricula and to train the next generation of leaders. The project interweaved educational research, graduate training, and teacher professional development focused on research with online TELS instructional materials that address difficult concepts in middle and high school science.

During the five years of funding, TELS reached more than 13,000 diverse students, 100 teachers, and their principals. TELS trained more than 40 fellows and nine post doctoral scholars. The TELS technology team created a new, Java-based infrastructure for designing, developing, and delivering computer-based curricula that can utilize sophisticated applications such as probeware and computational models. This technology is called SAIL/OTrunk. SAIL (2007), the Scalable Architecture for Interactive Learning has enabled the development of new software that responds dynamically to student actions and provides formative feedback to teachers so they can adjust instruction as needed. OTrunk is a set of standards that ensure interoperability of a wide range of components within the SAIL environment.

TELS used SAIL/OTrunk to create a new version of WISE for authoring and delivery. Using the knowledge integration framework, TELS researchers created 12 replacement modules and assessments aligned with instruction each requiring about one week of class time. Extensive research has demonstrated the effectiveness of TELS materials. In one study, two large time-delayed cohorts of students were tested in schools that serve English language learners, students underrepresented in science, and students receiving free or reduced price lunches. Using a knowledge integration rubric to evaluate constructed response items, TELS resulted in over a quarter of a standard deviation improvement compared to the control group (effect size: .32, $p<.001$). Multiple-choice questions were not able to detect this gain, demonstrating the value of constructed responses (Linn, Lee, Tinker, Husic, & Chiu, 2006). SLOPE will extend the TELS collaboration and build on this research.

Summary and Next Steps

SLOPE will link continuous assessment of students, interactions with teachers, and high stakes assessment using an online system. For a pilot study, we will focus on one middle school unit on motion for the pilot investigation. The motion unit is deigned by a partnership that includes both of the PIs on this preliminary proposal, two classroom teachers, and experts in assessment. We will use student embedded assessments that include: student reflection notes, student experiment plans, student experiment results, logs of student interactions with motion probes, and student collaboration in a brainstorm session. We will link this to teacher actions in the classroom, teacher review of student work, teacher feedback to students, teacher reflections on student progress, and teacher reflections on high stakes and embedded assessment. We will use high-stakes assessment items as pretests and posttests as well as embedding some items in the actual instruction. We expect to gather data in Fall 2009 and conduct analyses in Fall and Spring 2009-2010.

SLOPE has the potential to transform education by capitalizing on new sources of evidence about student learning and new teacher practices. Our pilot study will identify ways that these connections can succeed. We will use the pilot findings to write a more comprehensive proposal for large scale funding.

SLOPE will explore how this linking of student, teacher, and high stakes testing can add value to science courses. We will extend this effort to study how new users take advantage of the varied approaches to create a curriculum for their state, school, and students. We will link high stakes tests with continuous assessment practices and use the two sources to inform each other and to guide teacher practice.

How Graduate Students Learn To Be Scientists: The learning of research-specific mathematics

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Introduction

The National Science Education Standards (NSES) (National Research Council, 1996) state that students should understand the nature of science as inquiry and "requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science" (p. 105). The NSES also state that for teachers to be able to teach in this way, they should be "familiar enough with a science discipline to take part in research activities in that discipline" (p. 60). Few teachers have this knowledge or have had the opportunity to participate in scientific research activities. Accordingly, their students learn science as pre-packaged and delivered knowledge (Brickhouse, 1990; Flick, Lederman, & Enochs, 1996; Lederman, 1992). To remedy this situation, the NSES call for science learning experiences that involve teachers as researchers in scientific inquiry along with working scientists. This suggests that for teachers to teach their students how to do science, they should know how to do science.

I have been studying the ways in which graduate students and undergraduate honors students in science and engineering[3] learn to do science, as a way to inform the education of pre- and inservice science teachers. For example, in a previous study, my students and I examined the beliefs science and engineering professors have about the research education of their undergraduate and graduate students (Feldman, Divoll, & Rogan-Klyve, 2009). I now propose to conduct an interview-based pilot study of engineering and science graduate students (master's and doctoral levels) to begin to understand how they learn mathematics as part of their research activities. My previous study has shown that the graduate students do not take any courses after

[2] This address should be used beginning in August 2009.

[3] My observations of research engineers in a university setting suggests that way they do is more aligned with the idea of "science research" than the "engineering design process" that is being promoted in K-12 education. Therefore I use the term "science research" to refer to the activities of engineering graduate students and faculty.

they complete their comprehensive exams and do not enroll in any research methods classes except possibly a course on instrumentation. Although I do not have the data to support this claim, I believe that the engineering and science graduate students do little if any mathematics course work beyond what they did as undergraduates. However, it is clear from data from my previous study that the students learn new ways to work with numerical data. That is, they learn new mathematics. My goal, then, is to find out how they learn the mathematics as part of their graduate research education, and to use that knowledge to inform the education of pre- and inservice teachers.

Theoretical framework

Graduate study in science in the United States has two main components. The first consists of the accumulation of subject matter knowledge and the development of a deep conceptual understanding that occurs through coursework. The other is participation in research activities that leads to extensive knowledge of a subset of the subject domain, the learning of research skills, and the ability to frame and answer researchable questions. While the former occurs in the formal structure of an academic program, the latter usually occurs informally within a research community and can be understood as an apprenticeship process. In the proposed study, I use the concept of apprenticeship as legitimate peripheral participation in a community of practice that results in situated learning of the skills and knowledge needed to be a working scientist (Lave & Wenger, 1991)

The research group working in the laboratory can be thought of as a community of practice in which new members learn how to maintain the laboratory and the skills needed for experimental work, such as the *standard methods* published for each field (e.g., Clesceri, Greenberg, & Eaton, 1999). Even if there is no laboratory, the research group can be a community in which new practices are developed and shared with a larger community of practicing scientists (Creplet, Dupouet, & Vaast, 2003). However, to learn to be a scientist is more than learning how to be a skilled practitioner in the laboratory. Scientists also have as their goal to create and warrant new knowledge. As a result, the research group is not only a community of practice, it is also an epistemic community (Knorr Cetina, 1999) in which graduate students as legitimate peripheral participants attain the knowledge and skills needed to create and warrant new knowledge.

The theoretical framework of the proposed study also draws upon findings from the previous study. As expected, we found that:

- The education of new engineering and science researchers is informal and individual, and follows the structure of a traditional apprenticeship.
- The research groups were both communities of practice and epistemic communities.

We also we found that:

- The configuration of research groups and laboratories varied according to the research area.
- The professors had very different expectations for undergraduate, master's, and doctoral students, which led to our development of a typology of how students of engineering and science function as members of research groups. This typology includes: Novice Researchers who have little or no experience with scientific research; Proficient Technicians who have attained the knowledge and skills necessary to become skilled practitioners in their field; and Knowledge Producers who have the knowledge and skills needed to formulate their own research questions, to develop new research methods, and to add to the literature.
- The typology is developmental, with students potentially being able to move from Novice Research to Proficient Technician to Knowledge Producer (Feldman, et al., 2009)

Methods

The setting for the proposed study is a Research I university in the southern US. The university has strong science departments in which there are many active research groups, and an engineering college that also has many active research groups. There is also a graduate college of marine sciences. At this time it seems most likely that the initial group of student interviewees will be from the College of Engineering and the College of Marine Sciences because this is currently where I have my strongest connections.

Data collection

The primary data collection method will be interviews of graduate students who are pursuing research degrees. The interview will focus on their undergraduate preparation, their graduate course work, and how they gain knowledge and skills to engage in research activities in their research groups. Students will be selected for the interviews in such a way as to have at least one student from each of the three developmental levels that we identified in the previous study (i.e., Novice research, Proficient Technician, and Knowledge Producer) at least one engineering research group and one science research group. Interviews will be recorded and transcribed.

Data analysis

The data will be analyzed using the coding of qualitative data (Miles & Huberman, 1994) and through the construction of understanding inherent in the use of long and serious conversations as research (Feldman, 1999). Pre-conceived categories for coding will be derived from the research literature on graduate education and apprenticeships and from the previous study, while emergent categories will be derived inductively from the data, following the methods of the development of grounded theory (Corbin & Strauss, 2007). I will use the qualitative analysis software HyperResearch to help with the analysis.

Expected outcomes

I have two goals for this pilot study. The first is to identify engineering and science graduate students' sources of the mathematical knowledge that they use to engage in research. If, as I suspect, much if not most of that mathematical knowledge is gained as a result of its infusion in the process of learning to do scientific research, then I will use the results of the interviews to develop a survey instrument that can be used more broadly. The second goal is to begin to understand how that mathematical knowledge grows as a result of the infusion. A serious attempt at this second goal would require additional funding, and could be the basis for a proposal to the National Science Foundation.

Implications for K12 education

The previous study suggested that the way that people learn to become scientists who engage in the construction and warranting of new knowledge is by participating in activities that have characteristics of a community of practice and of an epistemic community. It appears that it is possible to become a proficient member of a community of practice by the end of a one or two year program. However, this is without gaining the knowledge and skills to be a knowledge producer. Thus, professional development models currently used, such as the National Science Foundation's Research Experiences for Teachers, may provide teachers with a "taste" of authentic science, but most likely cannot prepare them to be more than novice researchers. Therefore, if we want science teachers to have the knowledge and skills needed to teach their students how to engage in authentic science activities, they need to be engaged in research activities for more than a few weeks one summer. It also follows that K12 students would also need more time engaged in research activities if they are to be able to learn what it means to do science. If my research supports the idea that significant mathematical learning occurs when learning how to do science research, then it is possible that teachers and schools would be more willing to dedicate the time and resources needed to support students in long term, authentic science research activities.

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PERCEPTIONS OF THE MATHEMATICS CONTENT AND MATHEMATICS PEDAGOGICAL CONTENT KNOWLEDGE OF TEACHERS PREPARED AS MATHEMATICS AND SCIENCE GENERALISTS AND AS MATHEMATICS AND SCIENCE SPECIALISTS

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Overview of the Study

Problem

Traditionally, middle childhood/middle school teachers have been prepared as generalists (i.e., elementary school teachers) with limited science and mathematics content or as one-subject specialists with mainly mathematics and/or science content knowledge and pedagogical content knowledge. There is a need to identify and compare the perceptions of the mathematics content and mathematics pedagogical content knowledge of teachers prepared as mathematics and science generalists to that of mathematics and science specialists with a dual content (mathematics and science) preparation.

Research Question

What are the differences in the perceived importance and efficacy for mathematics content knowledge and pedagogical content knowledge between the generalist and dual content prospective and practicing teachers?

Rationale

There is a need for more students to be proficient and interested in STEM and STEM related fields. Teachers at the middle childhood/middle school level play an important role in the development of interest and proficiency in these fields. Since mathematics and science are fundamental components of the STEM fields, this study will focus upon the perceived importance and efficacy of existing teacher preparation programs for grade 4-8 teachers.

Literature Review

Preservice elementary teachers generally have poor mathematical knowledge (Ball, 1990; Goulding, Rowland, & Barber, 2002; Ma, 1999). Reports also indicate that these teachers have only a procedural understanding of fractions (Fuller, 1996); measures of central tendency, such as mean, median and mode (Groth & Bergner, 2006); and a poor grasp of concepts related to decimals (Stacey, Helme, Steinle, Baturo; Irwin, & Bana, 2001). In addition, preservice teachers focused almost exclusively on the procedural aspects when solving problems involving divisibility (Zazkis & Campbell, 1996), could not, for example, use diagrams to explain the interrelationships among numbers such as rational, integer, natural, real, and whole numbers (Adams, 1998); and did not possess a profound understanding of fundamental math—PUFM—

(Ma, 1999). Moreover, they held strong negative attitudes toward mathematics (e.g., MacNab & Payne, 2003).

Both intuition and research suggest that the mathematical content knowledge (MCK) of elementary teachers is related to their teaching ability and eventual student achievement. For example, Goulding et al. (2002) found that teaching performance of teachers in the United Kingdom was significantly correlated to MCK. In comparing the performance of students whose teachers had better mathematical preparation and knowledge than those whose teachers had less preparation and knowledge, Rowan, Chiang, and Miller (1997) found that the former outperformed the latter.

Studies on the effects of undergraduate mathematics courses on the mathematical content knowledge (MCK) and attitude towards mathematics of preservice elementary and high school teachers (e.g., Hill, Rowan, & Ball, 2005; Matthews & Seaman, 2007) report that teachers with better mathematical knowledge had students with better annual gains in mathematical knowledge but the effect of such teacher knowledge was more pronounced for students of low ability. Similar results seems to hold true for other countries (e.g. Harbison & Hanushek, 1992; Mullens, Murnane, & Willett, 1996; Tatto, Nielsen, Cummings, Kularatna, & Dharmadasa, 1993).

Studies also have documented that low income, minority students are more likely to have inexperienced teachers (Loeb & Reininger, 2004), teachers certified out of their teaching expertise (Strutchens, Lubienski, McGraw, & Westbrook, 2004), and teachers who have initially failed a certification exam (Loeb & Reininger). Indeed, Hill et al. (2005) demonstrated, using nonrandom samples of elementary teachers, significant correlation (both statistical and substantive) between teacher knowledge and student poverty status.

Given that NCLB requires "highly qualified" (HQ) teachers, the situation is exacerbated for middle school mathematics teachers, where discipline-specific (for example, mathematics) teachers are often former elementary school teachers certified as generalists, who need to upgrade their credentials to be deemed HQ, possibly through some combination of college courses and exams. The HQ provisions of NCLB also require that all students be taught by HQ teachers or failing this, that there is an equitable distribution of such HQ teachers in both high-poverty and affluent student school populations. However, evidence suggests that such an equitable distribution of HQ teachers is not the case, and that White and more affluent students are more likely to have better prepared and more knowledgeable teachers than are students of color or students with low SES.

In Hill's (2007) study, she explored middle school teachers' mathematical knowledge for teaching, i.e., pedagogical content knowledge (PCK, see An, Kulm & Wu, 2004; Shulman, 1995) focused on the teaching of mathematics and the relationship between such knowledge and teachers' subject matter preparation, certification type, teaching experience, and their students' poverty status. She found that those with more mathematical course work, a subject-specific certification, and high school teaching experience tended to have higher levels of PCK. Her study, too, confirmed that more affluent students are more likely to encounter more knowledgeable teachers.

While numerous studies have documented shortcomings in the mathematical knowledge of elementary school teachers (Ball, 1990; Goulding et al., 2002; Ma, 1999), the few extant studies of middle and high school teachers suggest that even relatively stronger collegiate subject matter preparation may be a necessary but not a sufficient condition of deep knowledge of the content taught to students (Ball, 1991; Bryan, 1999; Kahan, Cooper, & Bethea, 2003; Post, Harel, Behr, & Lesh, 1991; Swafford, Jones, & Thornton, 1997; Turnuklu & Yesildere, 2007).

Research on the attitude of preservice elementary teachers points to negative attitudes toward mathematics (Kolstad & Hughes, 1994; MacNab & Payne, 2003). Furthermore, efficacy has also been shown to be related to attitude toward mathematics (Randhawa, Beamer, & Lundberg, 1993). Since both MCK and attitude toward math seem to affect efficacy in teaching math, we now turn to studies documenting efforts to improve teachers' MCK and attitude toward mathematics.

Some of these studies have documented the impact of methods courses that emphasized both MCK and MPCK. Quinn (1997) found significant increases in MCK and attitude toward mathematics, as did Stoddart, Connell, Stofflett, and Peck (1993). However, (a) neither study compared results to a control group, (b) both had a testing effect limitation because the same instrument was used for the pretest and posttest data, and (c) neither study directly measured the effect of a mathematics content course (i.e., a course taught in a mathematics department), even though mathematics content courses might differ from methods courses in their potential to investigate mathematical concepts more deeply. Beswick (2006), too, found that preservice elementary teachers' attitudes and beliefs significantly changed for the better via a combination of content and methods courses.

Ference and McDowell (2005) reported on a middle level teacher preparation program based on the National Middle School Association (2002) position statement that identified eight essential elements of such programs: (a) collaborative partnership; (b) early adolescence; (c) middle level philosophy and organization; (d) middle level curriculum; (e) teaching fields; (f) middle level planning, teaching, and assessment; (g) field experiences; and (h) collaborative roles. Using these eight elements and the four cornerstones of their college's teacher education program--namely liberal arts education, cultural responsiveness, school-based practice and current technology--they redesigned their teacher education curriculum. Some of the highlights of the program were: regular, sustained, continuous field experiences, including in diverse school settings and cultures (more than 130 hours before the senior year, and 450 hours in the senior year); working in teams; and using Professional Development Schools;

Because methods course generally focus on teaching procedures (e.g., effective assessment procedures), rather than on the mathematics, it has been suggested that preservice elementary teachers take specialized mathematics courses (Conference Board of the Mathematical Sciences, 2001; Kilpatrick, Swafford, & Findell, 2001). The suggestion is that these specialized courses address the mathematics typically taught in elementary school from an advanced prospective.

Despite these guidelines, the mathematical content preparation of preservice elementary teachers still varies widely across the nation (Matthews & Seaman, 2007). Matthews and Seaman randomly chose 59 out of 1,297 higher education institutions listed at The Chronicle of Higher Education website, http://chronicle.com/, in April 2007, to get information about elementary education degree requirements for this sample. Eleven did not offer a degree in elementary education. Twenty-nine offered a degree and had at least one mathematics course specifically designed for preservice elementary teachers. Fourteen offered a degree but did not have this type of course, requiring a general mathematics course instead. Five were unable to be classified into the previous categories for a variety of reasons, such as insufficient course descriptions. Thus, in some programs, preservice elementary teachers take only general mathematics courses, such as statistics or college algebra; in other programs, they take specialized courses designed to specifically address elementary mathematics from an advanced perspective.

Because middle school mathematics is a critical gateway to high school course taking and college enrollment (Riley, 1997; Silva & Moses, 1990), knowing more about the relative mathematical knowledge required will be helpful in understanding how middle school teachers should be recruited and trained. The assumption seems to be that by the time preservice middle school mathematics teachers have completed their college mathematics coursework, they will have the deep understanding of school mathematics subject matter necessary for teaching that subject matter. However, we believe a case can be made for including specific opportunities to revisit and reconstruct (or perhaps construct for the first time) the content of the school mathematics subject matter that they are going to teach.

In their review of middle level teacher preparation programs, Ference and McDowell (2005) cite Gaskill who reported that there is growing recognition of the importance of middle school teacher certification as opposed to the traditional elementary or secondary certification, and 44 states now have some sort of middle level certification—with 18 offering endorsements, 11 offering endorsements and certification, and 15 offering certification. While there is a paucity of research attesting to the effectiveness of specialized middle level certification, the few studies in this area do indicate positive results. As cited in Ference & McDowell, Giebelhaus found that recent graduates of such programs stated that they were confident in transferring what they had learned to their first year of teaching in middle schools. Similarly, McCotter, Muth, Hart, and Lim reported that the majority of their 457 respondents expressed confidence in teaching middle school, mainly because of their field experiences during the program. Lockart and Butt reported that participants in a pilot middle level program stated that their program gave them confidence in their ability to teach middle school students.

Mathews, Basista, Farrell, and Tomlin (2003) reported on a program for the preparation of middle school teachers that required two areas of concentration chosen from math, science, language arts and social studies. Specifically for those choosing math and science, the program included integrated courses in math and science that focused on both content knowledge and PCK. That the program seems to be providing more math and science teachers is evidenced by the fact that over 90% of the licensure students are preparing to teach science *or* math, and over 50% are prepared to teach math *and* science.

In summary, the literature review suggests the following:

1. Elementary school teachers (preservice and inservice) have poor math content knowledge (MCK), which translates into negative attitudes toward mathematics, and ineffective teaching of mathematics.
2. Teachers with both MCK and MPCK (pedagogical content knowledge) had students with better annual gains in mathematical knowledge.
3. The mathematical content preparation of preservice elementary teachers varies widely across the nation.
4. Some programs, with teachers "specializing" in two or three subjects at the elementary/middle school level are more effective teachers of those subjects (e.g., in mathematics), compared to the traditional multiple-subject credentialed elementary school teacher.

Hence, it seems that more information on the perception of students currently enrolled in or who have recently graduated from teacher preparation programs regarding the delivery of and exposure to MCK and MPCK in these programs might contribute to the knowledge base of teacher preparation programs specializing in mathematics and one or two other subjects. This information may be helpful to improve mathematics teacher preparation programs, particularly at the middle childhood/middle school level, and ultimately improve student achievement and attitudes toward mathematics and STEM-related subjects.

Because of the wide variation in credentialing practices across the United States, where some states certify K-8 teachers to teach middle school, whereas others certify 5-8 or 7-12 teachers to teach middle school, we believe a good starting point is to compare preservice and inservice teachers from two universities, namely The Ohio State University and the California State University Los Angeles. The Ohio State University prepares middle childhood teachers to teach in two licensure areas: mathematics, reading and language arts, science, and/or social studies. We propose to focus upon preservice and inservice teachers whose areas of concentration are mathematics and science. In contrast, California State University Los Angeles prepares middle school teachers based upon a K-8 generalist content focus.

Few states have middle school licensure mandating two areas of concentration and the institutions to offer these programs. Moreover, the immediate problem seems to be middle school teachers who have been prepared as generalists (i.e., elementary school teachers) with limited science and mathematics content or middle school teachers who have been prepared as one subject specialists (i.e., secondary school teachers) with a focus on science content knowledge and science content pedagogical knowledge. Therefore, we suggest prioritizing the content knowledge and pedagogical content knowledge competencies recommended for a middle childhood mathematics teacher in terms of application to and importance for the science classroom.

To this end, we have developed an instrument based upon the mathematics content knowledge and mathematics pedagogical content knowledge recommended for middle childhood mathematics teachers. These competencies were derived from recommendations of the National Council of Teachers of Mathematics with additional recommendations from the State of Ohio Department of Education. They include recommendations for mathematics preparation and teacher preparation related to professional knowledge, curriculum, instructional management, professional culture, and assessment. The purpose of this instrument is to be able to identify critical mathematics content and pedagogical content knowledge competencies along with areas in need of preparation for prospective and current middle school science teachers to advance the infusion of mathematics into the middle school science classroom. The instrument targets two dimensions: (a) Importance to the Science Teacher and (b) Preparation of the Science Teacher. The instrument can be used by teachers, administrators, teacher educators, and professional development providers. (See Appendix B for the instrument.)

Procedures

Data Collection Sites

The Division of Curriculum and Instruction at California State University at Los Angeles offers several programs leading to credentials for multiple and single subject teachers. The teaching credential with authorization in multiple subject instruction qualifies holders to teach in any self-contained classroom, preschool or kindergarten, grades 1 through 12. This credential requires 90 quarter units with a 2.75 GPA including 48 quarter units of professional education requirements.

The Middle Childhood (MC) Master's of Education Program for initial teacher preparation for middle childhood education (grades 4-9) offered at The Ohio State University is a 5-quarter post-baccalaureate program. The MC licensure program is designed to prepare teachers in at least two of the following areas of concentration: reading and language arts, mathematics, science, and social studies. A minimum of 33 quarter hours in mathematics content plus 6 quarter hours in mathematics methods or pedagogy are required to complete the mathematics area of concentration at the middle childhood level. The total credits for the middle childhood mathematics area of concentration is 39 quarter hours in addition to the 10 quarter hours required as general education requirements in the category of quantitative and logical skills. A minimum of 36 quarter hours in science content plus 6 quarter hours in science methods or pedagogy are required to complete the science area of concentration at the middle childhood level. The total credits for the middle childhood science mathematics area of concentration is 42 quarter hours in addition to the 15 quarter hours required as general education requirements in the category of natural laboratory science. As a Master's level program, the required GPA is 3.0.

Population/Sample

Preservice and inservice middle childhood science teachers will be identified and recruited from the K-8 generalist teacher licensure program at California State University (CSU) at Los Angeles and from The Ohio State University (OSU) Master's of Education Middle Childhood teacher licensure program. A total of 100 preservice and inservice teachers will be selected: 25 preservice and 25 inservice from CSU and 25 preservice and 25 inservice from OSU.

At the conclusion of the academic year, the preservice/inservice teachers will be asked to provide the demographic information and responses to the Mathematics Content and Mathematics Pedagogical Content Knowledge Preparation for Preservice and Inservice Practicing Science Teachers survey included in Appendix B.

The data from these responses will be analyzed to determine the respondents' perceptions of the importance of specific mathematics content knowledge for teaching middle school level mathematics in the science classroom as well as their perceptions of the importance of specific mathematics pedagogical content knowledge for teaching middle school mathematics in the science classroom.

In addition to the perceptions of importance, the preservice and inservice teachers also will be asked to indicate how well prepared they feel they are for both the mathematics content knowledge and the mathematics pedagogical content knowledge needed.

These data will be analyzed so as to compare perceptions of importance with perceptions of preparation. Comparisons will also be made between preservice and inservice middle childhood teachers, mathematics and science generalist teachers versus dual subject (mathematics and science) licensed middle childhood teachers, and combinations of these categories.

Anticipated Outcomes

The researchers expect there to be some discrepancy between what mathematics content knowledge the preservice and inservice teachers perceive as important and their opportunity and success for acquiring this knowledge. The outcomes from this pilot study are expected to provide insight into the perceptions of what the preservice and inservice middle school science teachers perceive as important for teaching mathematics within the science curriculum. It is expected that those preservice and inservice teachers that have experienced a dual content area licensure program or professional development experiences for science and mathematics will perceive greater levels of mathematics content knowledge and mathematics pedagogical content knowledge.

These results should provide guidance to science and mathematics teacher education programs as to what mathematics content and pedagogical content knowledge should be included and what knowledge needs to be more explicitly connected to the teaching of middle school science and mathematics. In addition, the results of this study can inform professional development efforts for inservice teachers as to what knowledge is perceived as important but not adequately provided for the teachers. What teachers perceive as very important and yet they do not perceive that they had the opportunity to acquire this mathematical knowledge or pedagogical content knowledge, can provide direction and guidance for teacher professional development and enhancement activities.

Timeline for Data Collection

Data Collection Timeline															
	2009 September	2009 October	2009 November	2009 December	2010 January	2010 February	2010 Mar.-May	2010 June	2010 July	2010 August	2010 September	2010 October	2010 November	2010 December	2011 January
	Identify subjects	Identify subjects	Recruit subjects	Recruit subjects	Prepare materials	Prepare materials		Administer instrument to inservice teachers		Administer instrument to preservice teachers	Analyze data & interpret results	Write report	Prepare proposal	Prepare proposal	Submit proposal

Figure 1. Timeline of prelim/pilot study project and proposal development for Federal funding.

Budget

See Appendix C for the budget for the proposed project.

Possible Next Steps

Research Agenda

Although we believe that teachers prepared to teach both middle school mathematics and science may be better able to infuse mathematics into the science classroom, a research agenda is needed to provide evidence and support for this position as well as identify teacher competencies and student outcomes. To this end, research should be designed to explore the following questions, appropriate for both preservice and inservice middle school science teachers.

1. What are the mathematics teaching resources, strategies, and activities used by middle school science teachers?
2. How can we measure middle school science teacher competences related to mathematics content knowledge and pedagogical content knowledge (see Center for Research in Mathematics and Science Teacher Development, 2006; Conference Board of the Mathematical Sciences, 2001; Hill, Schilling, & Ball, 2004; Mathematical Sciences Education Board, 1996 for a discussion of relevant issues and the development of new assessment measures).
3. What are the middle school science teacher competencies related to mathematics content knowledge and mathematics pedagogical content knowledge?
4. What are the middle school science teacher attitudes, perceptions, and dispositions related to mathematics?
5. What are student outcomes related to mathematics conceptual and procedural knowledge in a mathematics-infused science classroom?
6. What are student outcomes related to mathematics attitudes, perceptions, and dispositions in a mathematics-infused science classroom?
7. What is the support system (e.g., school organization, administrators, parents, community, assessment, financial resources) needed to facilitate the infusion of mathematics into the science classroom?
8. What are the changes in middle childhood science teacher perceptions related to the importance of and preparation for mathematics content knowledge and mathematics pedagogical content knowledge?

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APPENDIX A

Collaborators

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Appendix B

Mathematics Content Knowledge and Mathematics Pedagogical Content Knowledge Preparation for Preservice Prospective and Inservice Science Teachers

Mathematics Content Knowledge and
Mathematics Pedagogical Content Knowledge Preparation
for Preservice and Inservice Science Teachers

Name ________________________________ Date ______________________

Check all that are appropriate and list the subject(s).

________ Mathematics Teacher
Subject (s) ____

________ Science Teacher
Subject (s) ____

________ Mathematics Teacher Educator
________ Elementary School
________ Middle School
________ Secondary School

________ Science Teacher Educator
________ Elementary School
________ Middle School
________ Secondary School

________ Other ________________________________ (Please describe)

Check the levels that are appropriate to your future or current position:

________ Grade 1 ________ Grade 2 ________ Grade 3

________ Grade 4 ________ Grade 5 ________ Grade 6

________ Grade 7 ________ Grade 8 ________ Grade 9

_______Higher Education ______ Undergraduate ________ Graduate

<u>With regard to Middle School Science Teachers</u>,

from the following list of Mathematics Content Knowledge and Mathematics Pedagogical Knowledge circle:

VI Very Important **GP Generally Prepared**

MI Moderately Important **LP Limited Preparation**

NI Not Important **NP Not Prepared**

MATHEMATICS CONTENT KNOWLEDGE PREPARATION

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

39.	VI	MI	NI	use a problem-solving approach to investigate and understand mathematical content	GP	LP	NP	39
40.	VI	MI	NI	can communicate mathematical ideas in writing and orally, using everyday and mathematical language	GP	LP	NP	40
41.	VI	MI	NI	can make and evaluate mathematical conjectures and arguments and validate their own mathematical thinking	GP	LP	NP	41
42.	VI	MI	NI	can make connections among ideas in mathematics and connect mathematics to other disciplines and real-world situations	GP	LP	NP	42
43.	VI	MI	NI	use mathematical modeling to formulate and solve problems from both mathematical and everyday situations	GP	LP	NP	43
44.	VI	MI	NI	understand and apply concepts of number, number theory and number systems	GP	LP	NP	44
45.	VI	MI	NI	understand and apply numerical computational and estimation techniques and extend them to algebraic expressions	GP	LP	NP	45
46.	VI	MI	NI	understand and apply the process of measurement and measurement applications	GP	LP	NP	46
47.	VI	MI	NI	use geometric concepts and relationships, including transformations, to describe and model mathematical ideas and real-world constructs	GP	LP	NP	47

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

48.	VI	MI	NI	understand and apply the concepts of statistics and probability, including exploratory data analysis and experimental probability	GP	LP	NP	48.
49.	VI	MI	NI	use algebra to describe patterns, relations, and functions and to model and solve problems	GP	LP	NP	49.
50.	VI	MI	NI	understand the role of axiomatic systems in different branches of mathematics, such as algebra and geometry	GP	LP	NP	50.
51.	VI	MI	NI	explore the fundamental concepts of calculus through models, concrete examples, and use of calculators and computers	GP	LP	NP	51.
52.	VI	MI	NI	use algorithmic and recursive techniques in solving problems	GP	LP	NP	52.
53.	VI	MI	NI	use appropriate technology (including graphing calculators, spread sheets, and software packages) to explore and solve mathematical problems	GP	LP	NP	53.
54.	VI	MI	NI	have a knowledge of historical development in mathematics, including the contributions of underrepresented groups and diverse cultures	GP	LP	NP	54.

Mathematics Pedagogical Content Knowledge Preparation

Professional Knowledge

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

55.	VI	MI	NI	can identify and model strategies used for teaching the following strands for Middle Childhood: - problem solving	GP	LP	NP	55.
56.	VI	MI	NI	- numbers and number relations	GP	LP	NP	56.
57.	VI	MI	NI	- geometry	GP	LP	NP	57.
58.	VI	MI	NI	- algebra, patterns, relations, and functions	GP	LP	NP	58.
59.	VI	MI	NI	- measurement	GP	LP	NP	59.
60.	VI	MI	NI	- data analysis and probability	GP	LP	NP	60.
61.	VI	MI	NI	- estimation and computation	GP	LP	NP	61.
62.	VI	MI	NI	use calculators, computers, and other technologies as tools for teaching mathematics	GP	LP	NP	62.
63.	VI	MI	NI	use a variety of manipulative and visual materials for exploration and development of mathematical concepts for Middle Childhood	GP	LP	NP	63.
64.	VI	MI	NI	undergo the models for developing major concepts in grades K-3	GP	LP	NP	64.
65.	VI	MI	NI	develop mathematical concepts and procedures through interdisciplinary settings	GP	LP	NP	65.

Middle school science teachers -

(Circle one for each item.) **(Circle one for each item.)**

Curriculum								
66.	VI	MI	NI	use a variety of resource materials such as software, print materials, and activity files in the learning of mathematics	GP	LP	NP	66.
67.	VI	MI	NI	select appropriate mathematical tasks that will stimulate students' development of mathematical concepts and skills	GP	LP	NP	67.
68.	VI	MI	NI	plan mathematical tasks and activities for students who are culturally diverse, those with limited English proficiency, and those with special needs	GP	LP	NP	68.
Instructional Management								
69.	VI	MI	NI	use oral and written discourse between teacher and students and among students to develop and extend students' mathematical understanding	GP	LP	NP	69.
70.	VI	MI	NI	create a learning environment in which students feel free to take risks	GP	LP	NP	70.
71.	VI	MI	NI	use various student groupings such as collaborative groups, cooperative learning, and peer teaching	GP	LP	NP	71.
72.	VI	MI	NI	accommodate different learning styles such as visual, auditory, and tactile	GP	LP	NP	72.
Professional Culture								
73.	VI	MI	NI	apply knowledge of current research and national, *Ohio*, and local guidelines relating to mathematics instruction	GP	LP	NP	73.
74.	VI	MI	NI	recognize the role of reflective practice, professional development, and active participation in the community of learners to their life-long growth as a teacher	GP	LP	NP	74.
Assessment								
75.	VI	MI	NI	use assessment in the classroom to monitor students' mathematical learning and to make instructional decisions	GP	LP	NP	75.
76.	VI	MI	NI	use a variety of methods to assess mathematical learning, such as open-ended questions, portfolios, and performance tasks	GP	LP	NP	76.

APPENDIX C

Budget

Budget

Printing

125 copies of the 4-page instrument @ $ 0.05/copy =	$ 25.00

Communication

Telephone conferences 4 @ $35.00 =	$ 140.00

Personnel

California State University Co-Principal Investigator (1) for 3 days @ $300.00/day =	$ 900.00

- Subject identification
- Subject recruitment
- Data collection and organization
- Reporting

The Ohio State University Co-Principal Investigators (2) For 3 days @ $300.00/day =	$1800.00

- Subject identification
- Subject recruitment
- Data collection and organization
- Data analysis
- Reporting

Total	$2865.00

STEM PRELIMINARY PROPOSAL

Assessing STEM Knowledge at the High School Level

Mitchell J. Nathan

University of Wisconsin-Madison

The Problem

As the U.S. strives to meet the needs of a globalized, knowledge-driven economy, and shifts from a manufacturing-based economy to one that overwhelmingly provides services and information, technological skills must be integrated with academic knowledge of science, mathematics and the humanities, so that the next generation of leaders and workers can reason adaptively, think critically, and be prepared to learn how to learn (NRC, 2007). In the US, the reauthorization of the Perkins Vocational Education Act mandated that technical education and academic math and science topics must be integrated so "students achieve both academic and occupational competencies" (Pub. L. 101-392). Mathematics is specifically recognized for its singular importance for modeling and generalization. Contemporary forms of Career and Technical Education (CTE) are framed as addressing recent mandates that academic math and science instruction must be integrated with technical education so students advance both academically and occupationally. There is mounting evidence, however, that high school pre-college engineering classes within CTE programs may do little, in the aggregate, to advance students' mathematical achievement despite the additional time and effort students spend performing technical activities.

A multilevel statistical analysis (students nested under teachers) was conducted using school district data for an ethnically diverse (57% African American, 22% Hispanic, 12% White, 4% Asian, and 4% Other), urban, student body with a high proportion (72%) of low-income families using student enrollment patterns, and student and teacher characteristics (Tran & Nathan, under review). Although students generally showed gains from 8th to 10th grade ($p < 0.01$), students enrolled in the *Project Lead the Way* (PLTW) pre-college engineering courses exhibited statistically significantly lower gains ($p < 0.05$) on a Wisconsin state standardized math assessment than control students who did not participate (Figure 1). Also, students in and outside of PLTW showed comparable gains on science assessment scores when controlling for prior achievement and other student demographics (Figure 2). There were no differences among those PLTW students who were enrolled in one or more than one course ($p = .96$). These findings are in contrast to the expectation that *PLTW* enrollment contributes to higher math and science achievement.

One methodological concern is that the state assessments in math and science stop at 10th grade. It is reasonable to hypothesize that positive impact of PLTW on math and science might not show up until later grades. This may be because the forms of thinking need more time to mature, or that the engineering education may have a greater effect on later math and science conceptual development.

Background

PLTW is a national pre-college engineering curriculum that is used in over 1,400 US high schools. Through careful analyses of curriculum materials, teacher professional development materials, and videotaped classroom interactions, it is possible to distinguish between the *potential* opportunities that arise for mathematics to be connected to technical and design activities, on one hand, and the *explicit* connections that are made, on the other.

The notion of STEM education implies an integrative curriculum that reveals a synergy beyond the constituent parts (Schunn, 2009). However, while mathematics instruction has become more applied in many cases, science, technology and engineering has moved further away from the mathematics. A powerful set of examples can be seen in recent content analyses of K-12 pre-college engineering curricula. One detailed analysis of the three-year PLTW high school curricular core sequence revealed that very few math content standards are addressed (Nathan, Tran, Phelps, & Prevost, 2008). Further analyses of the planning and teacher training materials, course materials and classroom activities, and course assessments showed that the explicit integration of math concepts with regards to engineering concepts in all three *PLTW* courses was apparent, but weakly so (Prevost et al., 2009). Explicit integration was operationalized as any instance wherein the student curricula, teacher training materials or classroom-based instruction specifically point to a mathematics principle, law, or formula, and depict how it is used to carry out or understand an engineering concept, task or skill. A lack of integration between mathematics concepts and pre-college engineering activities and instruction is especially problematic given the cognitive science research that emphasizes the importance of explicit integration of ideas for successful transfer of knowledge. While there were many i*mplicitly embedded* opportunities for creating connections between the math concepts and the engineering activities and topics, many of these opportunities were not explicitly stated, and were therefore likely to go unaddressed in the classroom. Another study (Welty et al., 2008) analyzed twenty-two K–12 pre-college engineering curricula, including nine high school programs. The analysis explored the mission and goals of each curriculum; the presence of engineering concepts; and the treatment of mathematics, science, and technology. Particularly striking is "the noticeably thin presence of mathematics" in pre-college engineering curricula, where "very little attention was given to using mathematics to solve for unknowns. Furthermore, little attention was given to the power of mathematical models in engineering design."

Descriptive analyses of classroom observations over several days in PLTW classrooms revealed the nature of instruction and classroom interactions (Nathan, Oliver et al., 2009). Though the sample size is small, these preliminary findings revealed that: (1) more of the instructor's time was spent on class management (non-instructional) tasks than on any other classroom activity in order to accommodate the project-based nature of the classes; (2) a greater proportion of the total observed instruction time was devoted to skills rather than concepts, and (3) only a small fraction of instruction that linked math concepts to engineering coursework made those links explicit, while the large majority of math concepts were implicitly embedded in the classroom activities and the professional CAD software and tools used in the class.

Analyses from these various sources show that instances of explicit integration of mathematics concepts are quite rare, as suggested by earlier studies. This led to the formulation of three competing hypotheses that were subsequently tested: (a) CTE Facilitation, as motivated by the Perkins Act, that enrollment in high school pre- engineering courses would predict measurable gains in standardized math and science achievement scores from middle school and high school; (b) CTE Disconnect, as motivated by prior research, that achievement gains will not be evident due to the lack of explicit integration; and (c) CTE Impediment, that interference from pre-engineering or a deepening reliance on advanced computational tools could lead to slower test-taking performance, confusion, or even misconceptions that hinders student performance.

A multilevel statistical analysis (students nested under teachers, using alpha = .05) of school district data was conducted (Tran & Nathan, under review) on student enrollment patterns, along with prior (8th grade) and later (10th grade) math achievement for an ethnically diverse, urban, student body (Milwaukee, WI) with a high proportion of low-income families who were eligible for free or reduced lunch prices through the National School Lunch Program (72%). The analysis (N = 140) revealed no support for the CTE Facilitation Hypothesis. Controlling for both student and teacher characteristics, CTE course enrollment was associated with a statistically significantly *lower gain* in performance on math achievement scores from 8th to 10th grade (Figure 1). Science achievement scores also showed a smaller gain from 8th to 10th grade, though the decrease did not reach the level of significance (Figure 2). For math, the evidence is most consistent with the CTE Impediment Hypothesis. Teacher years of experience did not explain the variation of student achievement across teachers. Misalignment between course content and assessment content cannot be the central factor since all students in the data set took the same tests.

Proposed Work

While these findings will need to be replicated (we are doing just that with another urban school district; Tran & Nathan in preparation), these findings are limited because the standardized assessments stop at 10th grade. A more thorough study of the impact of engineering education on math and science needs to provide assessments at 12th grade, for all students. I propose to develop a grant proposal for NSF's Targeted MSP. In the proposal a framework would be developed regarding explicit integration of math and science for engineering content. This framework will (a) guide the construction of an assessment instrument for high school math, science and engineering content knowledge appropriate for all students, regardless of their CTE enrollment. The framework would identify the proper subject-specific and grade-specific concepts and procedures appropriate for later high school math and science, as well as integrated items for math-engineering (e.g., projective geometry from CAD) and science-engineering (e.g., traction forces for robotic vehicles) concepts and procedures. The project would use the students from the 10th grade cohort in 12th grade and see whether PLTW enrollment resulted in positive, negative, or neutral impact on achievement as compared to a matched cohort of non-PLTW students. The larger MSP will also: (b) develop the data management tools for school districts that will allow us to conduct the proper statistical analyses using school district data, and (c) design and implement a site-based professional development program at schools administering PLTW that would address the needs of explicit integration of high school math and science within engineering activities.

Here I emphasize goal (a), the assessment development. The work plan for this project (as it would be presented in the MSP proposal) follows:

1. **Fall Year 1.** Review prior research literature on assessment instruments for high school math, science and engineering, and draw on the Knowledge Integration Framework by Linn and colleagues (Linn, Lee, Tinker, Husic, & Chiu, 2006).

2. **Spring & Summer Year 1.** Develop the Explicit Integration Framework that will guide the design of the STEM Assessment Battery.

3. **Fall & Spring Year 2.** Develop preliminary versions of the STEM Assessment Battery

    a. Field test these with a small number of CTE and non-CTE students using think aloud protocol methods to obtain concurrent reports during problem solving;

    b. Present these to teacher focus groups in pre-college engineering, math and science;

    c. Present these to college engineering admissions officers;

    d. Present these to curriculum developers in pre-college engineering (especially PLTW);

4. **Summer Year 2.** Redesign the STEM Assessment Battery.

5. **Fall Year 3.** Present a redesigned version of the STEM Assessment Battery to a statistically viable sample to establish reliability and validity.

6. **Spring & Summer Year 3.** Use the findings of the STEM Assessment Battery to inform the design of the teacher professional development program.

7. **Fall Year 4.** Test the effectiveness of the Battery to detect improvements from Year 3 sample for those students whose teachers did and did not participate in the professional development program.

8. **Spring & Summer Year 4.** Further analyses and write-ups. Recruitment of a national sample of schools for wider testing of the STEM Assessment Battery.

Discussion and Conclusion

While the pedagogical and cognitive issues surrounding the integration of math and science in CTE courses are not fully understood, indicators of poor integration between academic and pre-college engineering courses may reinforce the different skills and knowledge that is valued for vocational versus college preparation. This may also feed attitudes that inhibit the mathematical and scientific reasoning measured by the assessments, as students come to expect that the technology will or should do the thinking for them, an attitude that may be especially problematic for students already exhibiting low math achievement. This can create a climate within which CTE courses do little to contribute to gains in math and science assessments, or even foster declines in achievement, while still making strides in the specific curriculum objectives of technical education. A more thorough study that includes assessment in math, science and engineering in later years will put this program of research on firmer ground.

References

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Tables and Figures

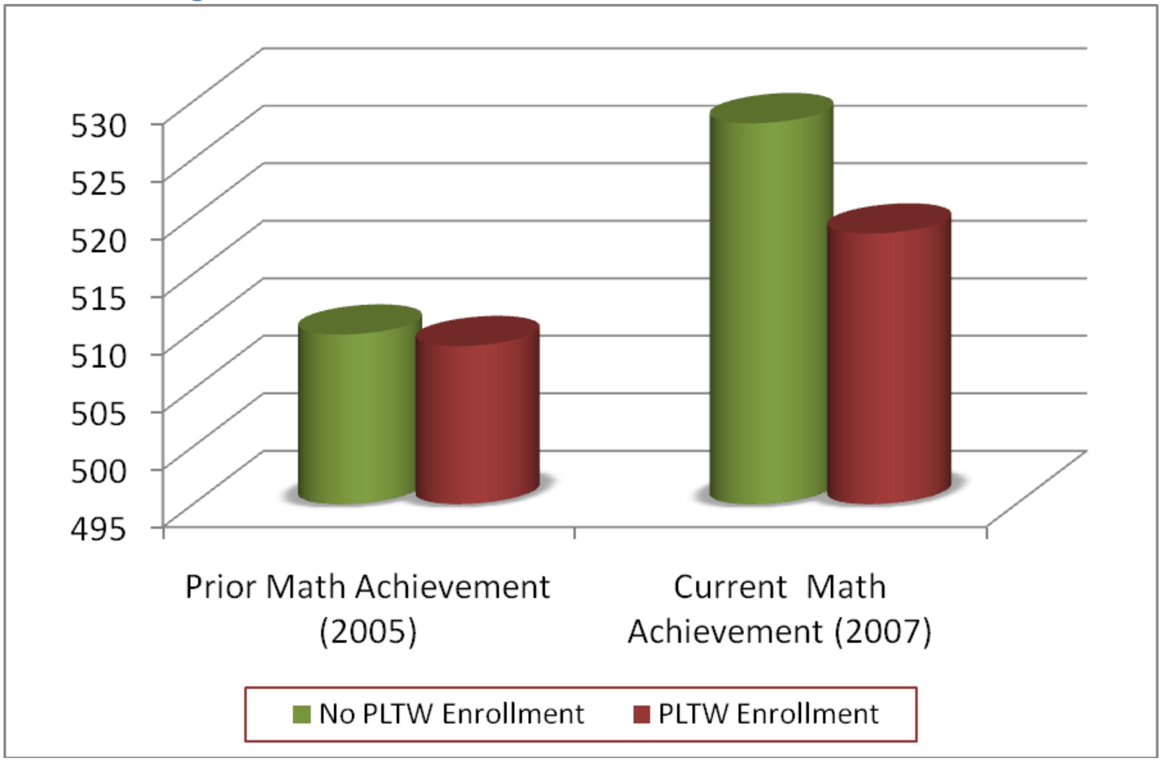

Figure 1. Math achievement.

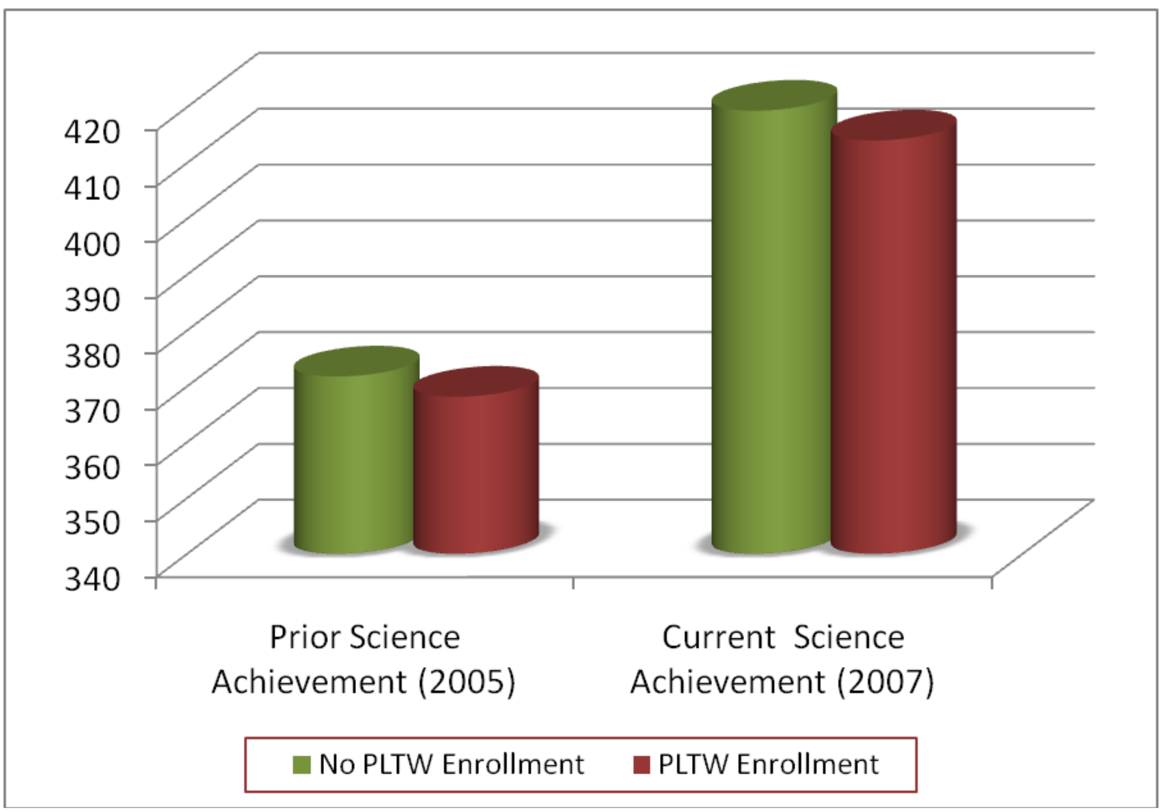

Figure 2. Science achievement.

WESTCONN STATE UNIVERSITY

STEM-ED

A Research Proposal submitted by:

Theodora Pinou, Ph.D., WESTCONN

Michal Lomask, Ph.D., CT State Department of Education

A project designed to enhance the teaching and learning of

Science, Technology, Engineering and Mathematics (STEM)

In Connecticut Elementary Schools

STEM-ED

Michal Lomask and Theodora Pinou

Vision

The world we are living in now has changed dramatically during the last half century and science, mathematics and technology became the center of that change – causing it, shaping it, responding to it. Knowledge and facility with these bodies of knowledge are essential to the education of today's children for tomorrow's world (American Association for the Advancement of Science, 1993). Empowering people to live productively in a world surrounded by scientific and technological advancements requires that the skills of scientific reasoning, mathematical problem solving and technological design and analysis be introduced to students in the early grades and be continuously supported throughout the entire school years.

Background

STEM education is an emerging field that deals with the application of various science, technology, engineering and mathematics (STEM) skills in order to explore and solve authentic STEM-related challenges. Instead of mashing the different disciplines into one integrated field, modern STEM education engages students in the discriminative application of various skills and ideas and the examination of their usefulness in dealing with different issues and questions. Currently all elementary school students have to learn mathematics, many have to learn science and few are engaged with technology and/or engineering. But review of common elementary school curricula and practices showed that students have limited opportunities to be engaged with and develop understanding of STEM content, ideas and skills. However, emerging research shows that students' achievement and motivation to learn traditional math and science can be increased by engaging them in project-based STEM learning (Burghardt and Hacker, 2008; Hammond, Pecheone and Vasudeva, 2009; Lomask, 1997).

Our proposed research and development project intends to create and plant STEM seeds in elementary schools in Connecticut and nurture the development of STEM knowledge of both students and teachers. We plan to create a new educational partnership between university STEM faculty and upper elementary (grades 3-5) teachers in several local school districts. The *STEM-ED partnership* will be dedicated to the development, implementation and exploration of teaching and learning in interdisciplinary STEM classroom environment.

Partnership Goals

The goals of this research and development grant proposal are to develop standard-based materials for STEM learning in elementary schools, engage elementary school teachers in the learning and teaching of STEM units and explore the impact of STEM instruction on students' academic performance and perception of math, science and technology. More specifically, the goals of the established partnership are:

a. Training a group of elementary school teachers as science, technology, engineering and mathematics (STEM) learning leaders by creating extended and interactive STEM-focused Professional and Collaborative Learning Communities (PCLC);

b. Development of extended curriculum-embedded STEM inquiry units;

c. Engaging students in lrarning of curriculum-embedded STEM activities;

d. Development of relevant evaluation tools (i.e., rubrics for the evaluation of students' performance, observation-based evaluation of teachers, attitude survey questionnaires);

e. Conducting research to study the impact of STEM learning on both teachers' and students' attitude and achievement in each of the STEM disciplines; and

f.. Revising Westconn's pre-service elementary math and science education courses, based on finding from this project.

Planned study

To make the STEM learning an integral part of the schools' curriculum in Connecticut, the planned STEM inquiry units will be directly related to the CT Core Curriculum Science Framework standards. In the first phase of the study the *STEM-ED* partnership will develop project-based learning units that are based on the state-sponsored grade 3-5 science curriculum-embedded performance tasks. The original science tasks will be extended to also include mathematics, technology and engineering design activities. In the second phase, the partnership will engage school teachers in learning the content and the content-specific pedagogy necessary to engage children in authentic STEM inquiries. In the third phase teachers will implement the developed STEM units in their classes (one STEM unit a year) and collect samples of student work. In the fourth phase the partnership will analyze student work and based on the findings will devise appropriate changes and instructional accommodations. In the fifth phase the partnership teachers will mentor a new cohort of school teachers and using electronic communication technologies (e.g., wikies, links, blogs) they will engage parents and the larger community in STEM learning.

Evaluation

The impact of the project on teachers' instructional practice and students' academic productivity will be measured through: a)standardized state-wide tests (e.g., student performance in the math and science CMTs); b) content-specific formative assessments (to be developed by the partnership) and c) surveys of teachers and students (to be developed by the partnership). Project evaluation will be based on a longitudinal model in which both teachers and students' performance will be evaluated before, during and after the teacher training workshops

Core partners

The *STEM-ED partnership* will include math and science faculty from Western Connecticut State University (Westconn), technology education faculty from Central Connecticut State University, and 25-30 grade three to five teachers from Danbury, Norwalk and Waterbury public schools. Project leaders will be Dr. Theodora Pinou (Associate Professor of Biology and environmental science/science method teaching at Westconn), Dr. David Burns (Associate professor of Elementary school mathematics at Westconn), and STEM school curriculum coordinators. Project support and evaluation will be done by Dr. Michal Lomask (retired CT state's science education/assessment development consultant). The project will engage additional STEM faculty, adult learning coaches and technology experts, as needed.

Action Plan:

The time line for proposed project activities includes:

1. Development of STEM curriculum-embedded performance tasks (summer of 2009)
2. Development of teacher and student evaluation instruments (Fall of 2009)
3. Collection of base-line data about teaching practices and student learning in the classes of the partnership teachers (winter 2009 and spring 2010)
4. Project leaders and faculty will train 35 teachers in grades 3-5 in STEM content and pedagogy (summer 2010);

5. Partnership teachers and leaders will develop the STEM formative assessment tasks (summer 2010);
6. Partnership teachers will implement STEM activities in their classrooms and collect student work (2010-2011 school year);
7. Monthly meetings of STEM faculty and teachers to analyze and discuss student performance and its connection to classroom STEM pedagogy (2010-2011 school year);
8. Development of task-specific evaluation rubrics (2010-2011 school year);
9. Analysis of student work and revisions of STEM activities (summer of 2011);
10. Scale-up implementation – every partnership teacher will coach another teacher in his/her school in the implementation of the revised STEM inquiry tasks (2011-2012 school year);
11. Classroom observations of STEM trained teachers and comparisons to base-line data (summer 2012);
12. Data collection from student STEM work/assessment and from students scores on the state-wide math and science CMT assessments (2012);
13. Data analysis and reporting of results
14. Sharing material through professional conferences and on-line educational sites (winter 2012)

Anticipated Outcomes and next Steps:

We anticipate that students of participating teachers will:

a. be motivated to learn and engage in the performance of the STEM tasks
b. will increase their understanding of the involved content
c. will increase their understanding of science inquiry, technology/engineering design and mathematical problem solving processes

We anticipate that the participating STEM teachers will:

a. improve their own STEM-specific pedagogical skills
b. will be able to integrate math, science and technology when appropriate
c. will develop STEM leadership skills and work collaboratively with school colleagues on STEM initiatives .

We anticipate that the project leadership will:

a. transform the current State’s embedded science tasks into STEM units

b. develop rubrics for the evaluation of student work in STEM projects
c. will share materials and results with the greater educational system

We anticipate that the participating universities will:

a. Use the STEM-ED Partnership materials in their courses
b. Prepare elementary teachers to better teach STEM subjects
c. Will start the process of developing STEM education courses and majors

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Appendix A

Components of technology literacy

(Standards for Technology Literacy, ITEA, 2007, p. 9)

Technologically literate people understand the major technological concepts behind current issues and appreciate the importance of fundamental technological developments. They are skilled in the safe use of technological processes that may be prerequisites for their careers, health, or enjoyment. Technologically literate people have a fundamental approach to technology:

- They are **problem solvers** who consider technological issues from different points of view and relate them to a variety of contexts.
- They understand **technological impacts** and **consequences**, acknowledging that solutions often involve tradeoffs, accepting less of one quality in order to gain more of another.
- They use a strong **systems-oriented, creative,** and **productive approach** to thinking about and solving technological problems.
- They use concepts from **science, mathematics, social studies, language arts**, and **other content areas** as tools for understanding and managing technological systems.
- They appreciate the interrelationships between technology and **individuals, society,** and **the environment**.
- They understand that technology is the result of **human activity** or **innovation**.

Appendix B
Technology Education Standards relevant to the STEM ED project

Standard A-3: Assessment of student learning will be systematic and derived from research-based assessment principles.

Guidelines for meeting Standard A-3 require that teachers consistently

A. Remain current with research on student learning and assessment.
B. Devise a formative assessment plan.
C. Establish a summative assessment plan.
D. Facilitate enhancement of student learning.
E. Accommodate for student commonality and diversity.
F. Include students in the assessment process.

Standard PD-1: Professional development will provide teachers with knowledge, abilities, and understanding consistent with *Standards for Technological Literacy: Content for the Study of Technology* (*STL*).

Guidelines for meeting Standard PD-1 require that professional development providers consistently prepare teachers to

A. Understand the nature of technology.
B. Recognize the relationship between technology and society.
C. Know the attributes of design.
D. Develop abilities for a technological world.
E. Develop proficiency in the designed world.

Standard PD-3: Professional development will prepare teachers to design and evaluate technology curricula and programs.

Guidelines for meeting Standard PD-3 require that professional development providers consistently prepare teachers to

A. Design and evaluate curricula and programs that enable all students to attain technological literacy.
B. Design and evaluate curricula and programs across disciplines.
C. Design and evaluate curricula and programs across grade levels.
D. Design and evaluate curricula and programs using multiple sources of information.

APPENDIX C:
Alignment of the Curriculum Embedded STEM tasks to the CT Grade Level Expectations(GLEs) in Science, Math and Technology.

Embedded Task	**Science** Grade Level Expectations	**Math** Grade Level Expectations	**Technology/Engineering** Grade Level Benchmarks
GRADE 3 - "SOGGY PAPER" <u>Summary:</u> In this performance task, students explore the water-holding properties of different types of paper. Through observation, a guided investigation and the design of their own experiment, students will learn that to make a fair test of different properties, certain things should be kept the same so that results are more reliable.	1. Design and conduct fair tests to investigate the absorbency of different materials, write conclusions based on evidence, and analyze why similar investigations might produce different results. 2. Describe ways people use earth materials, such as fossil fuels, trees, water, soils and rocks as natural resources to improve their lives. 3. Summarize nonfiction text to explain how humans use technology to access and use natural resources to produce electricity or other products (e.g., paper or concrete). 4. Use mathematics to estimate, measure and graph the quantity of a natural resource (e.g., water, paper) used by an individual (or group) in a certain time period. 5. Distinguish among reducing, reusing, recycling and replacing as conservation techniques.	1. Analyze, describe and extend repeating and growing patterns and sequences, including those found in real-world contexts, by constructing and using tables, graphs and charts. 2. Create and solve addition and subtraction word problems by using place value patterns and algebraic properties (commutative and associative for addition). 3. Pose questions that can be used to guide data collection, organization, and representation. 4. Collect and organize the data that answer the questions using diagrams, charts, tables, lists, pictographs, bar graphs and line plots	1. Tools, materials, and skills are used to make things and carry out tasks. 2. Creative thinking and economic and cultural influences shape technological development. 3. Resources are the things needed to get a job done, such as tools and machines, materials, information, energy, people, capital, and time. 4. When using technology, results can be good or bad. 5. The design process is a purposeful method of planning practical solutions to problems. 6. Requirements for a design include such factors as the desired elements and features of a product or system or the limits that are placed on the design. 7. The process of experimentation, which is common in science, can also be used to solve technological problems. 8. Test and evaluate the solutions for the design problem. 9. Improve the design solutions. 10. Processing systems convert natural materials into products. 11. Manufacturing processes include 12. Manufacturing enterprises exist because of a consumption of goods
GRADE 4 - "GO WITH THE	1. Construct complete (closed) and	1. Solve contextual problems involving addition and	1. Tools, materials, and skills are used to make things and carry out tasks.

FLOW” Summary: In this performance task, students explore ways that wires, batteries and a bulb can be arranged so that electricity will flow and light the bulb. Once they have discovered the concept of a circuit, they design and build a test circuit that can be used to find out which materials conduct electricity and which do not.	incomplete (open) series circuits in which electrical energy is transformed into heat, light, sound and/or motion energy. 2. Draw labeled diagrams of complete and incomplete circuits and explain necessary components and how components must be arranged to make a complete circuit. 3. Predict whether diagrammed circuit configurations will light a bulb. 4. Develop a method for testing conductivity, and analyze data to generalize about which materials are good electrical conductors and which are good insulators.	subtraction of whole numbers using a variety of methods, including writing appropriate number sentences (equations) and explaining the strategies used. 2. Create story problems to match a given number sentence (equation). 3. Use customary and metric tools and units and non-standard units to estimate, measure and solve problems involving length and perimeter to the nearest quarter-inch or half-centimeter, area, capacity, weight, temperature and volume. 4. Use estimation strategies to predict reasonable answers to measurement problems and explain the reasoning used orally and in writing. 5. Discuss, make predictions and write about patterns and trends in categorical and numerical data that have been represented in a variety of ways. 6. Determine the range, median, mode and mean of a set of data and describe characteristics of the data set as typical or	2. Creative thinking and economic and cultural influences shape technological development. 3. Resources are the things needed to get a job done, such as tools and machines, materials, information, energy, people, capital, and time. 4. When using technology, results can be good or bad. 5. The design process is a purposeful method of planning practical solutions to problems. 6. Requirements for a design include such factors as the desired elements and features of a product or system or the limits that are placed on the design. 7. The process of experimentation, which is common in science, can also be used to solve technological problems. 8. Test and evaluate the solutions for the design problem. 9. Improve the design solutions. 10. Processing systems convert natural materials into products. 11. Manufacturing processes include 12. Manufacturing enterprises exist because of a consumption of goods

		average based on those determinations	
GRADE 5 - "CATCH IT!" <u>Summary</u>: In this performance task, students explore factors affecting human reaction time. First, students use a technique for measuring the reaction time of different individuals, then students observe how long it takes group members to catch a falling ruler. Noting that people have different reaction times, students will explore possible factors that might influence reaction time speed. In both experiments, students will learn about the importance of controlling variables to make a fair test so that results are more reliable.	1. Explain the role of sensory organs in perceiving stimuli (e.g., light/dark, heat/cold, flavors, pain, etc.) and sending signals to the brain. 2. Pose testable questions and design experiments to explore factors that affect human reaction time. 3. Summarize nonfiction text to explain the role of the brain and spinal cord in responding to information received from the sense organs.	1. Analyze patterns and data to make generalizations, make predictions and to identify trends. 2. Solve length problems involving conversions of measure within the customary (inches, feet, yards and miles) or metric systems (millimeters, centimeters, meters and kilometers). 3. Represent sets of data using line plots, bar graphs, double bar graphs, pictographs, simple circle graphs, stem and leaf plots and *scatter plots*. 4. Compare different representations of the same data set and evaluate how well each kind of display represents the features of the data. 5. Design and conduct surveys of a representative sample of a population and use the data collected to begin to make inferences about the general population. 6. Determine the mean, mode and median of a data set and explain in writing, how they are affected by a change in the data set.	1. Tools, materials, and skills are used to make things and carry out tasks. 2. Creative thinking and economic and cultural influences shape technological development. 3. Resources are the things needed to get a job done, such as tools and machines, materials, information, energy, people, capital, and time. 4. When using technology, results can be good or bad. 5. The design process is a purposeful method of planning practical solutions to problems. 6. Requirements for a design include such factors as the desired elements and features of a product or system or the limits that are placed on the design. 7. The process of experimentation, which is common in science, can also be used to solve technological problems. 8. Test and evaluate the solutions for the design problem. 9. Improve the design solutions. 10. Processing systems convert natural materials into products. 11. Manufacturing processes include 12. Manufacturing enterprises exist because of a consumption of goods

Investigating Science Teachers' Attitudes about Math Infusion

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A recent study funded by the Bill and Melinda Gates Foundation yielded the unsurprising conclusion that the teacher is the most critical element of our society's public education system. The Long Island middle-school principal who told me this rolled his eyes when he said it, as if the study had all the impact of reporting that water is wet.

So educational researchers and practitioners apparently agree that the prospects of reform initiatives depend on participating teachers more than any other factor. Two implications are apparent here.

The first concerns teacher quality. Much has been written of late about the challenge of recruiting and retaining a high-quality teacher workforce. For many educators and commentators, reaching this goal is made more difficult by the widespread practice of conferring career-long tenure on teachers. It remains exceedingly difficult to remove a teacher for classroom incompetence; typically serious malfeasance (e.g., sexual harassment) is required for teacher-dismissal proceedings to move forward. Clearly, educational reform will have to work mainly through collaborating with the current workforce, not by replacing it.

That makes the second implication, teacher motivation, all the more important. If teachers support a reform initiative, and are motivated to participate in it, the sky's the limit. But the opposite is also true: when teachers are skeptical or disinterested, they can dilute or weaken a reform initiative, or kill it outright. Hence, a burgeoning body of research is focused on teachers' beliefs and attitudes, which go a long way to predict what kinds of outcomes educational reform initiatives are likely to produce.

One strand of this work deals with teachers' attitudes about professional development, since educational reform depends so heavily on teacher participation in PD programs. In general this work reveals teachers to be none too enthused about the PD programs in which they have participated (e.g., Borko, 2004; Little, 2001; Guskey, 2000; Richardson, 2003; Wei et al., 2009). Teachers are widely argued to have little esteem for PD programs, often regarding them as impractical, unsupported by school-district policies and practices, and delivered by presenters with limited or nonexistent classroom experience (e.g., Amos & Benton, 1988; Borko, 2004; Cochran-Smith & Lytle, 1992; Craft, 1996; Guskey, 2000, 2002; Little, 2001; Sparks and Hirsh, 1997, 2000; Richardson, 2003). What's more, research shows that support for PD programs is weaker in low-achieving schools than in high-performing ones (Torff & Sessions, in press).

Differences across subjects are also evident in teachers' attitudes about PD, research shows (Torff & Byrnes, in review). In this study, elementary teachers were most supportive of PD among all teacher groups. The least supportive teachers were in secondary education, and in particular, in science. Among all the teachers of different subjects taught in a typical school district, science teachers were far and away the most skeptical about PD programs.

This finding sounds ominous tones for educational reform initiatives that involve science teachers – such as the ongoing MSTP project at Hofstra. This project has revealed that students taught using a special curriculum featuring infusion of math concepts and procedures into science education produced higher math test scores relative to a control group taught without such infusion.

But just because an idea works does not mean teachers will take to it. Accordingly, researchers implementing the MSTP project report they have had their share of struggles gaining cooperation from science teachers at participating schools, with success in some instances but not others.

So the goal of promoting infusion of math into science faces considerable obstacles, in the form of science teachers' generally sour attitudes about PD. This conclusion points to the need for a pair of research initiatives, as described below.

Study #1: Science Teachers' Attitudes about Math Infusion

What attitudes do science teachers hold about math infusion? How do their attitudes about math infusion differ from their more general attitudes about PD? How do these attitudes change as a result of participation in a PD program centered on math infusion? How do these attitudes vary as a consequence of school achievement level (low-achieving versus high-achieving)? How do teachers of various sciences differ in these attitudes? And how do teachers' attitudes vary as a consequence of teacher characteristics such as age, gender, teaching experience, and educational attainment?

As noted, recent research indicates that science teachers are most resistant to PD among all teachers in public education (Torff & Byrnes, in review). But this research did not specifically mention math infusion as a PD topic, and attitudes about infusion may differ from attitudes about other topics. Moreover, it remains unclear how teachers' attitudes about math infusion differ from their more general attitudes about PD. There are data (collected in the MSTP project) on teachers' attitudes about infusion, but in this work more general attitudes were not assessed. (For this assessment the *Teachers' Attitudes about Professional Development* scale – TAP – can be helpful; Torff, Sessions, & Byrnes, 2005). Conversely, research on teachers' more general attitudes about PD (i.e., research employing the TAP scale) has not involved a specific focus on infusion. So it is not known how science teachers' beliefs about infusion differ from their more general attitudes about PD.

Neither is it clear how teachers' attitudes change as a result of participating in a PD program centered on infusion. There is evidence that successful PD programs can change teachers' attitudes; Byrnes and Torff (in press) report that teachers who participated in a PD program centered on "action research" (teacher-directed classroom research projects) have a more favorable attitude about action research than control-group teachers who had not participated. Infusion may produce a similar, positive result. Or it may not.

Method

The basic strategy for the research follows a two-phase design. In the first phase, the goal is to develop and validate the scores produced by a new survey instrument designed to measure teachers' attitudes about, self-reported capacity for, and prior involvement with infusion of math into science.

In the second phase, the new survey will be administered to two groups of science teachers: "control" teachers who have no prior involvement with math infusion (but will read a detailed description of it), and "treatment" teachers who have such a prior involvement (as a consequence of participating in Hofstra's MSTP project in the last five years).

Participants will include science teachers on Long Island and in New York City, hopefully about 150-200 in all. A matching procedure should be used, so that each MSTP-participating school is aligned with a similar school in the control group.

The survey should also include variables to be used as covariates and effects, including the following:

- The TAP scale, which measures teachers' more general attitudes about PD
- Science(s) taught (general science, earth science, living environment, chemistry, physics)
- School district achievement level (allowing comparison of teacher attitudes in low- and high-achieving schools)
- Gender
- Age
- Years of teaching experience
- Educational attainment (bachelor's, master's, master's plus 30, master's plus 60, doctorate)

It may also prove fruitful to administer items that ask respondents to compare math infusion to other common PD topics (e.g., differentiated instruction, motivation).

Data collection should ensure adequate representation of the five sciences and both low- and high-achieving schools. These data will be collected using procedures developed by the researcher in numerous survey-research projects in the past: by taking the survey to faculty meetings and asking participants to complete the brief instrument on the spot. Online surveys are nothing if not convenient, but they often produce intractable response-rate problems (raising issues of sampling validity, especially concerning self-selection). Taking the surveys to faculty meetings may be labor intensive, but it obviates the response-rate problem.

Data analysis will initially involve examining the factor structure and internal-consistency reliability of the infusion-attitude survey and the TAP scale. Assuming these prove satisfactory, additional analyses might well include regression modeling, with the infusion-attitude factor scores used as the outcome variable and all other variables (including TAP) entered as predictors. It may also prove useful to employ general linear models and discriminant function analysis to explore how the treatment and control groups compare and contrast.

Ultimately, this research will determine the extent to which teachers who have participated in an infusion-based pilot project differ in attitudes relative to teachers who have not participated. It will also explore the extent to which teachers' attitudes about infusion are a function of their more general attitudes about PD, controlling for various variables (e.g., educational attainment) that might contribute significant variation to the infusion attitudes. The study will also determine the extent to which teachers in different schools (i.e., low- and high-achieving) differ in attitudes about math infusion (controlling for the other variables). These results have potential to inform future PD programs designed to promote math infusion among science teachers.

Study #2:
Exploring Science Teachers' Resistance to Professional Development

Why are science teachers so resistant to PD relative to other teachers? What is it about the PD experience that has soured them? What needs to be done to make PD programs more palatable for them? What do they have to say specifically about math infusion as a PD topic? How could math infusion PD programs be structured to gain their support? To what extent do teachers of different sciences (e.g., earth science, physics) differ in their responses to these questions?

All PD programs depend on teachers' willingness to innovate their practice. Exploring why science teachers are resistant will lead to PD programs that (a) are more effective in producing classroom improvements, and (b) help improve teachers' attitudes about PD, starting to reverse an unfortunate legacy.

The project might well involve a set of four steps:

Initially the goal will be to specify candidate factors. The researchers will conduct interviews or focus groups with science teachers, asking them to nominate (a) factors that have influenced their responses to the PD events they have attended, and (b) factors that would likely influence their responses were they to be incorporated in a future PD program. These factors should be collected for PD in general and for math infusion in particular.

Second, the researchers will distill from the interviews/focus groups a set of factors (again, for PD in general and for math infusion in particular), and load these into survey instrument. Included with this survey instrument will be the variables listed under Study #1 above, for use as covariates and effects.

Third, the researchers will administer the survey to hundreds of science teachers, disaggregating them by type of science taught. The strategy of taking the instrument to faculty meetings seems in order, for the same reasons cited above.

Finally, the researchers will validate the scores produced by the survey using factor analysis and internal-consistency reliability analysis. Regression analysis can then be employed to determine how different factors are associated with teachers' attitudes about PD.

The results of this sequence of steps have potential to shed light on what is now a dark corner: why science teachers are resistant to PD, and what to do about it. The results will also provide insight concerning science teachers' attitudes about math infusion, and how it can best be packaged to encourage widespread use.

Ultimately, these two studies have potential to inform the design, implementation, and evaluation of PD program innovations aimed to promote math infusion into science instruction – and also to improve both PD program effectiveness and science teachers' attitudes about PD.

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Exploring the Merits of Teaching Engineering Principles and Ways of Thinking Under the Auspices of STEM Education

A Pilot Study Submitted by:

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Engineering is a significant human endeavor that permeates culture, underpins the quality of life, and facilitates technological progress. Young people preparing for life, work, and citizenship in a society inundated with technology can benefit from a fundamental understanding of the nature of engineering. A rich treatment of basic engineering principles and ways of thinking can help students translate seemingly sophisticated technologies into manageable sets of ideas, actions, outcomes, and consequences that can be understood and appreciated.

Engineering draws heavily on mathematics, science, and technology (domain knowledge) to inform the development of solutions to problems. In addition to applications of mathematics, science and technology, the study of engineering includes noteworthy concepts like design, analysis, constraints, modeling, optimization, and systems. Furthermore, engaging students in engineering design requires them to think deeply about the problems that they are attempting to solve. They must tap their existing knowledge to begin formulating potential solutions to the problem, and then seek answers to the questions that emerge during the engineering design process. Furthermore, as novice engineers, they must use their new knowledge to develop their ideas into products, processes, or systems that can be tested. The results of the testing process validate the knowledge used to solve the problem or inspire the need to refine or revise one's thinking even further. In short, engineering design activities require students to activate prior knowledge, seek and integrate new knowledge with existing knowledge, use new knowledge in conjunction with existing knowledge, and reflect upon their learning experience. Therefore, the thought processes required to design products, processes, or systems are parallel to those required to learning something new.

The Problem

A landscape study of current science, technology, engineering, and mathematics (STEM) curricula concluded engineering is currently playing a variety of roles in public education (Welty, 2008). At present, engineering is being used to address the declining status of technology education and the lack of inquiry-based learning in science. It is also serving as a means to make science and mathematics more engaging, interesting, concrete, and relevant. In some cases it is about creating new products and solving problems. In others instances, it is clearly the study of an important human endeavor that underpins our quality of life. Often it is simply course work that teaches domain knowledge with little attention given to engineering principles or habits of mind. It is also seen as a means of feeding the engineering pipeline with candidates who have more preparation in mathematics and science. In the process of serving so many different functions, it is not clear if K-12 engineering education is truly addressing the essence of engineering in ways that make it accessible and meaningful to all students.

Engineering is an intrinsically interdisciplinary enterprise. However, the treatment of the mathematics was especially thin and under-developed despite the fact that it plays such an integral role in engineering. With the exception of design, the curriculum analysis process found little evidence that basic engineering principles are being targeted directly with substantial depth. Engineering practices like predictive analysis, modeling, and optimization currently receive very little attention even at the secondary level. Similarly, there was very little emphasis placed on addressing economic constraints. Relatively little attention is given to the ideas of reverse engineering of everyday objects, asking students to engineer simple things and processes to make the mathematics and science more accessible, and using case studies to depict the many facets and complexities of engineering.

Most of the materials available for STEM education were designed based on considerations other than engineering. Some are all about engaging students in more scientific inquiry. Others are all about engaging students in problem solving for the sake of problem solving. Still others are all about teaching technology as a subject. Very few are genuinely dedicated to teaching young people about the nature of engineering and its contributions to civilization and the human condition. Many of the authors of these materials reported that they did not take their lead from nature of engineering, but rather from a problem or opportunity in public education. As a result, bits and pieces of the engineering enterprise are being tapped and the balance is being left out (e.g., mathematics, economics).

The findings of this inquiry suggest that the potential of studying engineering in the general education curriculum has not been fully realized. Therefore, there is a need to determine the feasibility and benefits of teaching engineering principles and ways of thinking under the auspices of STEM education. More specifically, the proposed study aspires to address the following questions:

1. What are the salient characteristics of a model for teaching and learning that targets the nature of engineering and, while addressing important concepts and processes from science, technology, and mathematics?
2. In what ways does the utilization of engineering design as a pedagogical strategy have a positive impact student learning?
3. Does the study of engineering principles and habits of mind contribute to student achievement and dispositions in the areas of science, technology, and mathematics?
4. What are the obstacles that inhibit the study of engineering as an integral part of STEM education?

Methodology

The primary purpose of this pilot study is to explore the potential contributions that the study of engineering principles and ways of thinking can play in STEM initiatives. More specifically, the researchers aspire to test the proposition that engineering design problems can be used to help middle school students understand concepts and develop skills from science, technology, engineering, and mathematics.

Research Design

A case study approach will be used to capture and describe the impact that engineering instruction has on teachers and students. Case studies are especially appropriate for this line of inquiry because they address questions about "how" and "why" related to complex endeavors that offer little or no opportunities for control (Stake, 1995; Yin, 2003). More specifically, a multiple–case design with embedded lines of inquiry will be used to organize the investigation (Bogdan & Biklen, 2003; Merriam, 1998; Yin, 2003). Three modules featuring engineering concepts and ways of thinking will be implemented in three different locations. They will render three sets of data regarding the feasibility and impact of engineering-based instruction (see the table below). The embedded lines of inquiry will examine the characteristics of engineering experience that support teaching and learning, the pedagogical value of engineering design activities, the relative contributions that engineering design activities have on the development of selected concepts and skills from STEM disciplines, and the obstacles that temper the introduction of engineering instruction at the middle school level.

Researchers	Case Study Topics	School Settings	Teachers
Marie Hoepfl	TBA	TBA	TBA
Mark Sanders	TBA	Christiansburg or Blacksburg Middle School	Linda Morales-Burton or Stephanie Crawford
Kenneth Welty	Structural Engineering	Brillion Middle School, Brillion WI	Steve Meyer

Each case will be initiated with an engineering design problem that represents a different branch of engineering to aid in establishing the validity of the ideas underpinning the instruction. However, all the engineering design problems will engage students in developing a simple device that involves the following experiences.

Mathematics	Conducting calculations using grade-level algebra and geometry to inform the engineering design process.
Science	Applying grade-level physical science principles, concepts, and procedures to the development of viable solutions to technical problems.
Analysis	Conducting systematic and detailed examinations to define problems, evaluate alternatives, predict performance, determine economic feasibility, and evaluate designs.
Constraints	Identifying and addressing the physical, economical, aesthetic, and time limitations inherent to and imposed upon the design problem.

Modeling	Utilizing graphic, physical, and mathematical representations of the essential features of a system to inform the engineering design process.
Optimization	Pursuing the best possible solution to a problem that contains competing or conflicting factors and involves balancing trade-offs.
Systems	Configuring collections of discrete elements (e.g., parts) that are designed to work together in interdependent ways to perform a function.

Each of the concepts listed above can be aligned with current learning theories (e.g., constructivism, meta-cognitive strategies, social interaction). A model for utilizing the study of engineer to facilitate student learning will be developed. The model will depict how to use engineering concepts and ways of thinking to translate prominent learning theories into classroom practice. For example, prominent learning theories suggest prior knowledge and experience play critical roles in the learning process. Therefore, the proposed model will feature engineering learning activities that focus on simple problems derived from everyday life in contrast to complex scenarios that require specialized domain knowledge. Similarly, the model will capitalize on engineering problems to provide authentic contexts for applying algebra principles by giving the numbers (variables) and the relationships (formulas) concrete identities and representing mathematics patterns with tactile experiences. Research also suggests asking students to represent challenging ideas in different ways contributes to understanding. Consequently, the proposed model will promote learning by engaging students in developing and using mathematical, graphic, and physical models during the course of the engineering design process. These and other concepts and theories will be developed into a framework that can be used to design, implement, and evaluate instruction that leverages the study of engineering to encourage student learning.

The model will be designed to address professional development needs for those developing and implementing engineering-based learning activities. The initial model will be submitted to a panel experts comprised of one or more persons representing learning science, engineering, engineering education, technology education, science education, and math education. Their task will be to review the model, critique its validity, and offer revision suggestions. The panel's feedback will be used to refine the model, after which it will be resubmitted it to the panel for further input. The refined model will be used to develop, implement, and evaluate the engineering instructional activities that will use for the remainder of this study.

Development

The research will require the development of three pieces of instruction that can be implemented in middle school classrooms over the course of 10 days under the auspices of STEM education (hereafter referred to as modules). They will be designed to address salient ideas about the nature of engineering (e.g., modeling, optimization, system) as well as the role of mathematics and science in engineering. Each module will feature a design problem that calls for defining a problem in operational terms from a given scenario, developing mathematical models to inform design decisions and predict performance, applying relevant science concepts to the development of a viable solution, building physical models or prototypes that can be tested, gathering and interpreting data to evaluate the design in relation to the design specifications, and presenting the results of their work to others. Throughout the design process, students will record their ideas, questions, data, and discoveries in engineering notebooks that are configured to aid the teaching and learning process as well as provide the researchers useful data.

The module development process will begin with a series of semi-structured interviews with groups of middle school students. The purpose of the interviews is to solicit students' conceptions and misconceptions about the nature of engineering and the roles that science, technology, and mathematics play in engineering endeavors. The development process will also be informed by multiple rounds of input from the teachers implementing the modules in their classrooms and laboratories. In draft form, the modules will be submitted to multiple technology, engineering, science, and mathematics educators to critique their representation of science, technology, engineering, and mathematics content. Their feedback will be used to refine the modules and ultimately, to establish their face validity. Lastly, since the classroom teachers participating in this initiative are integral to the investigation, they will receive the professional development needed to understand the nature of the research being conducted, to implement the modules in accordance with their theoretical design, and to contribute their perspectives and insights to the case studies.

Settings and Subjects

The study will be conducted in technology education classrooms and laboratories in the middle schools participating in the study (as defined in the previous table). The study will be conducted in required classes to ensure the data collected reflects a cross section of students (e.g., gender, academic ability, socio-economic status, talents, interests). The courses will be eighth-grade level so the learning activities can be aligned with instruction and content standards related to physical science and algebra.

Data Gathering and Analysis

A case study approach will enable the researchers to study engineering-based learning activities in public school settings using multiple sources of evidence and triangulation in a manner that is grounded in and guided by theoretical propositions. A modified analytic induction approach will be used to test the proposition that engineering design problems can foster achievement in STEM disciplines. This approach will involve implementing the design activities with multiple groups of students in the three settings during the second quarter of the school year. Topics of interest will include how the students think through their engineering problems; the extent to which the students understand the engineering, mathematics, and science concepts embedded in the problem; and much more. Quantitative and qualitative data will be collected through written exams, direct observation, student and teacher interviews, and audits of student work. The data will be used to compare the students' performance on multiple measures with the objectives that the activities were designed to achieve. The results of this analysis will be used to revise the teaching and learning model underpinning three design problems and to inform subsequent instruction, refine the learning activities, and improve future implementations.

A second round of implementation and data collection activities will occur during the fourth quarter of the school year to test the revised model. Once again, the modules will be implemented with new sets of students in the same middle school classrooms and with the same teachers. Data collection will be through direct observations, teacher and student interviews, reviews of student work samples, and student assessments. The data will be analyzed to identify critical incidents, reoccurring themes, and salient patterns related to the variables outlined in the research questions. One of the outcomes of this inquiry will be three documented stories that derive from experience, illuminate the problematic merger of theory and practice, and report the insights gained based on evidence in a manner that is both thought provoking and telling. The findings will be used to formulate a series of conclusions, implications, and recommendations for further study of engineering at the middle school level.

Beyond the Pilot Study

Each module from the pilot study will be developed for and implemented in a specific school setting to test the proposition that engineering-based activities can contribute to the achievement of objectives in science, technology, engineering, and mathematics. The results of the pilot testing process will render insights about the characteristics of effective engineering instruction, the impact engineering design activities have on achievement in STEM disciplines, the pedagogical power of engineering design, and the challenges that must be addressed when introducing the study of engineering at the middle school level. The strength of the conclusions derived from these cases will be a function of the three discrete learning activities that are implemented in three discrete schools. The next logical step is to implement all three modules in all three schools to determine their utility in different schools that are in different locations with different teachers and students. Once again, the inquiry would involve collecting data via direct observations, teacher and student interviews, student work samples, and student assessments. The results of this inquiry would lead to further refinements of the instructional model that underpins the three modules and add validity to the conclusions drawn. The work would culminate in the dissemination of the findings and conclusions of the study.

Projected Timeline

Summer 2010

1. Conceptualize three unique engineering problems in terms of their science, technology, engineering, and mathematics content.
2. Develop interview schedules and aids for conducting interviews with middle schools students to identify their conceptions and misconceptions about engineering and the roles that science, technology, and mathematics play in engineering endeavors.

Fall 2010

3. Conduct interviews with middle school students in the schools participating in the research study.
4. Align the content associated with the engineering problems with the content taught in the science, technology, and mathematics curricula.
5. Solicit input from the participating teachers regarding the content and learning activities featured in the engineering modules.
6. Implement each engineering module during the second quarter of the school year in at least two sections of required technology classes at the eighth grade level.

	7. Gather data through assessment tools, direct observations, teacher and student interviews, and audits of student work.
Spring 2011	8. Analyze the data gathered during the first implementation of the engineering modules.
	9. Use the findings of the first implementation to revise the teaching and learning model underpinning the engineering modules.
	10. Refine the engineering modules to reflect the revised teaching and learning model and to improve their utility as a research tool.
	11. Implement the refined engineering modules during the fourth quarter of the school year in at least two sections of required eighth grade technology classes.
	12. Gather data through assessment tools, direct observations, teacher and student interviews, and audits of student work.
Summer 2011	13. Analyze the data gathered during the second implementation of the engineering modules.
	14. Use the findings of the second implementation to further revise the teaching and learning model underpinning the engineering modules.
	15. Refine the engineering modules to reflect the revised teaching and learning model.
	16. Compose narratives that report each case study in manner that includes assessment data, critical observations, participant testimony, and samples of student work.
	17. Analyze the results all three case studies to revise the teaching and learning model that was used to compose the engineering modules.

Projected Budget

Personnel	
• Three principal investigators with .05 FTE	$125,000.00
• Three graduate assistants with .25 FTE	$21,000.00
• Fringe benefits - principal investigators	$50,000.00
• Fringe benefits – graduate assistants	$6,300.00
Non-personnel	
• Services and supplies	$6,000.00
• Travel	$9,000.00
Total Direct Cost	$217,300.00
Indirect Costs (50+/-percent depending on the institution)	$108,650.00
Total	$325,950.00

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Research Proposal

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Attitudes of Secondary Mathematics Teachers toward Professional Development

The current educational climate in the United States is driven by an overriding concern for student achievement. The role of teachers in student achievement is central to this concern. According to recent research conducted by the United States Department of Education (2007), “Teachers are the single most important factor in raising student achievement” (p. 1). Thus, current concerns for higher accountability of teachers and student assessments are major consequences of the push for greater student achievement.

School administrators are highly aware that professional development (PD) is a critical link between improved educational practice and student achievement (Knapp, 2003). Yet, teachers themselves are often resistant to PD opportunities (Wei, 2009; Borko, 2004). Consequently, the primary goals of this proposed research will be to survey the attitudes of in-service secondary mathematics teachers (grades 7-12) toward PD and to obtain their preferences regarding the design, structure, content, and timing of professional development opportunities. Results will be applied in the design of more beneficial and appealing PD opportunities for secondary mathematics teachers.

Design

This proposed research study will be conducted during the Fall Semester of 2009. It will consist of a web-based survey of approximately 150 randomly selected in-service mathematics teachers (grades 7-12) employed in public schools located in the regions of metropolitan New York City and the Long Island area. A table of random numbers from the RAND Corporation will be employed for the random selection of participants. This sample will be chosen in order to make inferences concerning the population of in-service secondary mathematics teachers from the regions of metropolitan New York City and the Long Island area.

Randomly selected in-service teachers will be invited, via e-mail, to participate in a survey of their attitudes toward professional development. A web-link of the survey instrument will appear on the participant's e-mail. This link, provided by Hofstra University, will allow participants to complete the survey instantaneously on-line. Participants will be informed that the survey will remain anonymous and that results will be accessible only to the researcher for the purpose of designing more beneficial professional development opportunities for teachers.

Instrumentation

The survey instrument to be employed in this research will be an adaptation of a professional development questionnaire, designed in 2005 by Hofstra University professors Bruce Torff, David Sessions, and Katherine Byrnes. This instrument was shown to be both valid and reliable. Specifically, results indicate that the survey instrument, *Teachers' Attitudes about Professional Development* (TAP), "produced scores with high reliability, a stable one-factor structure, and satisfactory construct and discriminate validity" (Torff, et al, p. 914). For the purposes of this research, the TAP instrument will be modified to focus specifically on secondary mathematics and to include four open-ended questions addressing teachers' preferences for the design, structure, content, and timing of professional development (PD) opportunities. One of these questions will seek participants' input regarding the infusion of content linkages and problem-based learning activities associated with the sciences, technologies, and other related fields. (See attachment.) Thus, the revised TAP scale will provide both numerical and anecdotal data.

Four open-ended questions will provide anecdotal data that will be analyzed by qualitative procedures. Responses to these questions will be vital to the creation of more appealing and beneficial professional development opportunities for secondary mathematics teachers.

Quantitative data, derived from the revised TAP survey instrument, will be analyzed using correlation and multiple regression techniques to measure the extent of relationships among three independent variables and one dependent variable.

Definition of Terms

Professional Development, according to the National Staff Development Council, "is a comprehensive, sustained, and intensive approach to improving teachers' effectiveness in raising student achievement" (p.1).

Highest Level of Academic Achievement refers to the highest college degree obtained by a participant in the areas of mathematics or mathematics education.

New York State Regents Mathematics Examination is a summative mathematics assessment that is administered to students at the conclusion of a NY State mathematics course.

Years of Full-Time Teaching refers to the total number of years a participant has taught the content of secondary mathematics on a full-time basis.

Statistical Procedures

The *Statistical Package for the Social Sciences* (SPSS) outlines a statistical procedure, technically known as *step-wise multiple regression*, which may be used to analyze quantitative data to determine the relationship between a dependent variable and a set of independent (or predictor) variables. Using SPSS, the researcher of the proposed study will employ step-wise multiple regression techniques to determine a prediction equation that indicates how the following three *independent variables*:

- Teachers' highest level of academic achievement in mathematics education (HAA),
- The school's performance on the New York State Regents' mathematics examinations (NYR),
- Years of full-time teaching (YFT),

can be weighted and summed to obtain the best prediction equation of an in-service secondary mathematics teacher's overall attitude toward professional development. This overall attitude toward professional development will be designated as the *dependent variable* (APD) for the study. The step-wise multiple regression procedure will further reveal the accuracy of the prediction equation and the amount of variation in teachers' attitudes toward professional development (APD) which may be accounted for by the joint influences of the three independent variables, HAA, NYR, and YFT. In this regard, it may be possible to simplify the prediction equation by deleting certain independent variables which have been shown to contribute insignificantly toward prediction accuracy, once other independent variables have been included.

Hypothesis testing procedures employing the F-ratio will be used to test for: (1) the overall goodness-of-fit of the derived regression prediction equation, (2) the significance of specific regression coefficients corresponding to HAA, NYR, and YFT, respectively, and (3) the significance of various combinations of multiple regression coefficients.

Hypotheses

The statistical hypotheses tested in the proposed study and stated in the null form are as follows:

Hypothesis One. There is no significant relationship among the three independent variables,

- Teachers' highest level of academic achievement in mathematics education (HAA),
- The school's performance on the New York State Regents' mathematics examinations (NYR)
- Years of full-time teaching (YFT)

and the dependent variable, overall attitudes of in-service secondary mathematics teachers toward professional development (APD).

Hypothesis Two. There is no significant relationship between HAA, (while controlling for the NYR, and YFT) and the overall attitudes of in-service secondary mathematics teachers toward professional development (APD).

Hypothesis Three. There is no significant relationship between the NYR (while controlling for the HAA, and YFT) and the overall attitudes of in-service secondary mathematics teachers toward professional development (APD).

Hypothesis Four. There is no significant relationship between the YFT (while controlling for HAA and NYR) and the overall attitudes of in-service secondary mathematics teachers toward professional development (APD).

Hypothesis Five. There is no significant relationship between selected combinations of the HAA, NYR, and YFT, respectively, and the overall attitudes of in-service secondary mathematics teachers toward professional development (APD).

Next Steps

The next steps of this research will be the creation of professional development programs that are more attractive and beneficial to secondary mathematics teachers. Hopefully, these data will support an initiative for the infusion of problem-based science activities and technologies into the secondary mathematics curriculum. Improved professional development programs, informed by this research, will be incorporated into future NSF proposals for funding of teacher enhancement projects in secondary mathematics.

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Teacher Opinion Questionnaire [TAP revised]

1. **Age**: _____

2. **Gender**: (Check one) ____female ____male

3. **Years of full-time teaching experience:** _________

4. **Highest level completed in mathematics/education**: (check one & specifiy major)

____ bachelors	____ masters plus 60 credits
____ masters	____ doctorate
____ masters plus 30 credits	Major:______________________

5. **Course you teach**: (Check the highest level course you teach during the school day.)

____ 7th grade mathematics	____ Integrated Algebra & Trig. (or Math B)	
____ 8th grade mathematics	____ Pre-calculus	
____ Integrated Algebra	____ Statistics	_____ Other (Specify)
____ Integrated Geometry	____ Calculus	_________________

6. **Your school's pass rate on the NYS Regent's exam (or other summative evaluation instrument) for the course checked in item 5 above.** ________________________

Please give your personal opinion about each or the following statements by circling the appropriate number to the right of each statement. This is an opinion questionnaire – there is no "right" or "wrong" answer. Your answers will remain confidential.

<u>Key</u>:

1 = strongly agree	4 = disagree slightly more than agree
2 = moderately agree	5 = moderately disagree
3 = agree slightly more than disagree	6 = strongly disagree

1. Professional development workshops often help teac to develop new teaching techniques	**1 2 3 4 5 6** *agree* *disagree*
2. If I did not have to attend inservice workshops, I would not	**1 2 3 4 5 6** *agree* *disagree*
3. Professional development events are worth the time they take	**1 2 3 4 5 6** *agree* *disagree*
4. I have been enriched by the teacher training events I have attended	**1 2 3 4 5 6** *agree* *disagree*
5. Staff development initiatives have NOT had much impact on my teaching	**1 2 3 4 5 6** *agree* *disagree*

Open-ended questions concerning the design, structure and content of PD activities:

7. What is your preferred focus of professional development activities in secondary mathematics? (e.g., technology-enhanced instruction, problem-based learning, mathematics content enhancement, integrated math curriculum, standards-based instruction/ assessment, collaborative learning, etc.)

   ____

8. When would you prefer that professional development activities take place? (e.g., after school, in the summer, whole days, half days, on weekends, over the Internet, etc.)

   ____

9. a. Do you think it is important to participate in professional development activities concerned with content linkages in the sciences, technology, economics, the arts, etc.? ____

   b. Do you think it is important to participate in professional development activities with peer teachers from other content areas (outside of mathematics) who frequently apply mathematical concepts in their courses ?

   ____

10. In sum, please convey any other individual preferences with respect to the design, structure, and content of professional development opportunities in secondary mathematics.

   ____