

**AC 2008-867: PARTNERSHIP TO IMPROVE STUDENT ACHIEVEMENT  
THROUGH REAL WORLD LEARNING IN ENGINEERING, SCIENCE,  
MATHEMATICS AND TECHNOLOGY**

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# **Partnership to Improve Student Achievement through Real World Learning in Engineering, Science, Mathematics and Technology**

## **Abstract**

Through a state-sponsored Math-Science Partnership (MSP) program, elementary teachers in New Jersey are receiving professional development in innovative, research-based, science and engineering curricula; classroom-based technical and pedagogical support; and ongoing coaching and mentoring. Two universities, a science center, and a teacher education institution are collaborating on delivering project services to schools. The program is strengthening the science content knowledge of 56 Grade 3-5 teachers in six urban districts in northern New Jersey. Preliminary findings from the pre and post tests of experimental group teachers indicate that participants significantly increased their content knowledge in specific life science topics and concepts involving the engineering design process. A study between the experimental and comparison group of teachers indicated a significant difference between the achievements attained by the two groups. This paper describes the first year of a three-year effort.

## **Introduction**

The Partnership to Improve Student Achievement (PISA) project is a New Jersey Department of Education-sponsored Math-Science Partnership (MSP) grant, which derives from a U.S. Department of Education (USED) grant. USED MSP program goals focus on strengthening teacher content knowledge in science and mathematics in order to improve student achievement in these subjects. The involvement of science, technology, engineering, and mathematics (STEM) faculty at institutions of higher education is a requirement of all MSP grants. The PISA program presents a novel approach to accomplishing MSP goals by integrating the use of exemplary, research-based elementary engineering curricula, engineering explorations and problem-based activities to strengthen teachers' science learning. An intensive summer institute, followed by in-class mentoring and coaching support, and online help, represent key program interventions. An important component of the project design is the requirement that teachers work in groups on the design of a STEM Learning Module (SLM) that incorporates science, mathematics, and technology toward the solution of an engineering problem. In creating this SLM, teachers engage in professional inquiry related to STEM content, pedagogy, assessment, and curricular resources relevant to the engineering challenge they are implementing or creating. Teachers work collaboratively on developing the module, including identification of student science learning objectives (tied to the district science curriculum and standards), lesson plans, implementation and classroom management plans, and student assessments.

The overarching aim of the three-year PISA program is to: (a) demonstrate and institutionalize within participating schools a methodology, supporting curriculum materials, and other instructional resources and strategies to increase student interest, engagement, and achievement in science, mathematics, engineering, and technology and further, to (b) promote a culture of inventiveness and creativity that calls upon students to demonstrate 21<sup>st</sup> century workforce skills and to apply science and mathematics toward the solution of relevant, real-world problems. Key

outcomes include: increasing the number of highly qualified teachers in elementary science classrooms in partner schools; use of inquiry-based science and of research-based, interdisciplinary, hands-on curricula and instructional strategies for science and engineering in classrooms of all participating teachers; and, increased student learning of science topics and processes, technology, and engineering.

## **Background**

There is a widening gap in math, science and engineering achievement between American students and those in other developed and developing countries. In a recent international assessment of mathematical problem-solving skills by 15-year-olds, the U.S. had the smallest percentage of top performers and the largest percentage of low performers among the participating developed countries<sup>1</sup>. Trends reported by the National Science Board<sup>2</sup> show that there are not enough students in the pipeline today to support the workforce of tomorrow. By 2005, the number of engineering degrees awarded in the U.S. had fallen by 20% compared to 1985. Today the number of engineering graduates in America is one-fifth the number of graduates in India and less than one ninth the number in China. The decreasing numbers of students completing degrees in engineering could have a serious effect on the science and engineering workforce of the United States unless more sufficiently prepared students, especially females and minorities, begin studying engineering in college<sup>3</sup>. Also of critical importance in the contemporary workforce are such technological literacy skills as designing, developing, and utilizing technological systems; working collaboratively on problem-based design activities; and applying technological knowledge and ability to real-world situations<sup>4,5</sup>. These skills are increasingly recognized by business, higher education, and policy leaders as critical for tomorrow's workforce<sup>6</sup>.

These concerns challenge teachers and policy makers to improve teaching, learning, teacher preparation programs, and professional development programs. Teachers play a major role in the classroom. They also have the ability to create and mold the environment where students can effectively learn. "A teacher knows something not understood by others, presumably the students. Moreover, the teacher can transform understanding, performance skills or desired attitudes or values into pedagogical representations and actions"<sup>7</sup>. Unfortunately, inequalities in the qualities of instruction and qualifications of teachers and resources result in widely different learning opportunities for different group of students<sup>8</sup>. In 1999, between 23% and 29% of public middle school and high school mathematics and science teachers lacked the qualifications or did not have the academic background in the subject they were teaching<sup>2</sup>. Most teachers teaching engineering as part of the K-12 curriculum lack the knowledge about what engineering is and how they might teach the subject<sup>9</sup>. At the same time, most teachers attended only few hours of professional development programs and most programs available to teachers are lacking the content, continuity, and depth to make meaningful changes in their teaching behaviors<sup>2,10</sup>.

This MSP program was developed to help teachers of Grades 3-5 with little or no science background gain new insights and increase their understanding of scientific and engineering concepts so that they will be prepared to teach science and associated engineering applications with skill, knowledge and confidence. Our hypothesis is that the professional development of teachers will have an impact on student learning of science topics and processes, technology, and

engineering. The program was designed to integrate engineering/technology and science in a way that supports the learning in each of these disciplines. Engineering complements the instruction of science by supplying a context for application outside of the science lesson.

### **Curricula Content and Structure of Teacher Professional Development**

Each year of the three-year MSP program focuses on a different science discipline. The first year, which ends in June, 2008 focuses on life science, environmental science and technology. Table 1 shows the New Jersey Core Curriculum Content Standards covered in the first year. Subsequent years will focus on earth science and physical science.

The professional development program each year consists of an 80 hour summer institute, three professional development workshops throughout the school year, classroom visits throughout the school year and online support. The program is jointly conducted by Stevens Institute of Technology, Montclair State University, Liberty Science Center and Bank Street College of Education, and include higher education faculty in science, engineering, and education, science professional development specialists, education specialists, and science museum education staff. The professional development program incorporates the design of a two- to three-week STEM Learning Module (SLM) that teachers can use in their classroom. The SLM that teachers develop includes: (1) two to three key science and mathematics topics that their students find difficult (based on teacher baseline surveys), (2) active student learning in a hands-on, team oriented project, (3) the engineering design process, and (4) an analysis of student learning to improve the SLM design.

**Table 1: New Jersey Core Curriculum Content Standards Covered in Year 1**

<b>NJ Curriculum Standard</b>	<b>Description</b>
5.5 Characteristics of Life	All students will gain an understanding of the structure, characteristics, and basic needs of organisms and will investigate the diversity of life.
5.10 Environmental Studies	All students will develop an understanding of the environment as a system of interdependent components affected by human activity and natural phenomena.
8.2 Technology Education	All students will develop an understanding of the nature and impact of technology, engineering, technological design, and the designed world as they relate to the individual, society, and the environment.

At the end of Year 1, all teachers will have received in-depth, content specific, pedagogical support, at least 124 hours of continuous professional development suggested by multiple reports and studies to bring about “a meaningful change in teaching behaviors,”<sup>2, 10, 11</sup> and frequent (monthly) on-site support (coaching, modeling, curriculum alignment, planning) by project partners. The production of a SLM through collaboration and in-depth/ topic-oriented

professional development will promote teacher's pedagogical content knowledge specifically in STEM areas<sup>7, 11</sup>.

Faculty lectures, demonstrations, and inquiry-based learning activities provided teachers with university-level content in specific topics in life and environmental sciences. Key topics addressed included: water quality, insects, and biological systems. The Museum of Science, Boston's *Engineering is Elementary (EiE)* curricula was used as the vehicle to help teachers apply their learning to a real-world problem and to introduce teachers to the engineering design process. The EiE curricula integrate engineering and technology concepts and skills with elementary science lessons. EiE materials engage students in hands-on, real world engineering experiences that can enliven science lessons and motivate students to learn concepts by illustrating relevant applications. Students use the Engineering Design Process to complete a design challenge presented at the end of each module. In an earlier pilot study conducted in New Jersey using the EiE curricula, it was found that teachers' confidence and understanding of engineering improved as a result of engaging in professional development and using the materials. Moreover, teachers felt much more comfortable with aspects of teaching engineering, including: designing, implementing, assessing, and determining relevant design features of engineering processes<sup>12</sup>. Similarly, pilot assessment of students revealed that engagement with EiE units raised their understanding of engineering concepts and processes. Specifically, based on the pre- and post-tests, students improved their understanding on what are human-made, technology, engineering work/careers, and engineering design process<sup>12, 13, 14</sup>.

### Summer Institute Program Content

In July 2007, approximately 60 elementary teachers worked together, guided by STEM faculty and K-12 professional development staff to successfully create STEM Learning Modules that they planned to use during the 2007-08 school year. Teachers designed their SLM around one of the EiE modules. The SLMs contain key science concepts and unit plan activities that teachers shared with each other and planned to implement in their classrooms. They were created and written using the 5E Model (Engage, Explore, Explain, Elaborate, and Evaluate) and reflect the science and engineering content and pedagogy that the participants learned in the summer workshops. Overall, the SLMs that the teachers created incorporated: (a) active student learning, (b) team-based approaches to teaching, (c) computer-based technology in the lesson, (d) the engineering design process, and/or (e) inquiry approach to teaching and learning science.

Because of the diverse group of participants, the goal was to cover a number of topics in life and environmental sciences (NJCCCS 5.5 and 5.10) to ensure that summer institute content found its way into teachers' classrooms during the 2007-08 school year and impacted teaching and learning. Scientific inquiry and the engineering design process provided the focus and coherence to the topics and concepts that were covered during the institute. The engineering activities provided the participants a hook to learn science. Moreover, the EiE curricula and associated training helped teachers to become comfortable in teaching engineering to promote science, creativity, critical thinking, and innovation.

During the planning stage for the summer institute, the challenge of presenting "university-level science content" to elementary teachers lacking science content backgrounds (as identified by the

grant guidelines) was identified. To address this challenge, a variety of activities at different levels of content/instruction were created and presented and multiple formative assessments (e.g. daily evaluations, discussions, and questions) were used to gauge how accessible the science content and its presentation were to our participants.

Daily workshops consisted of a variety of activities focused on the topics of life and environmental sciences. Activities included:

- Presentations by Engineering Faculty:

Lectures, laboratory tours, and hands-on activities were conducted by biomedical, environmental, and chemical engineering faculty who presented university-level science content.

- Demonstration and Practice with EiE Modules:

- a) *Best of Bugs: Agricultural Engineering* - Students learn about the role of insects in the natural system of pollination and the concept of Integrated Pest Management. Students design a hand pollinator.
- b) *Just Passing Through: Bioengineering* - Students learn about the ways bioengineers use their knowledge about the basic needs of organisms when designing technologies. Students design a model membrane
- c) *Water, Water, Everywhere: Environmental Engineering* - Students explore the role that environmental engineers in providing and maintaining water quality. Students design a water filter.

- Exploration of Internet-based Resources:

These included elementary level real time data and telecollaborative projects in life and environmental science as well as other online teacher and student tools and resources. See [http://www.stevens.edu/ciese/pisa/life\\_science.html](http://www.stevens.edu/ciese/pisa/life_science.html) .

- Modeling of Life Science Lessons:

Modeled by professional development staff and designed to help teachers gain a clearer understanding of the inquiry process. Topics included making and using dichotomous keys for plant and animal identification and designing a water run-off investigation.

- Development of a STEM Learning Module:

Participants were guided through the process of developing a STEM learning module incorporating the science and engineering concepts that were introduced during the institute. Completed modules were posted to the project website and teachers are expected to implement the activities during the 2007-2008 school year. See [http://www.stevens.edu/ciese/pisa/learning\\_modules.html](http://www.stevens.edu/ciese/pisa/learning_modules.html) .

- Presentations by Education Faculty:

Lectures, hands-on, and modeling activities in the areas of science literacy, critical thinking and problem-solving were conducted by education faculty.

### School Year Professional Development, Classroom Visits and Online Support

During the 2007-08 school year, three follow-up workshops focused on additional science content were held: *Water and the Environment*, *Developing Scientists in Your Classroom*, and *Plant and Animal Life Cycles*. Teachers engaged in hands-on exploration activities and also had the opportunity to share classroom implementation successes and challenges with other teachers.

A significant part of the MSP project is devoted to in-class support for teachers to help them plan and complete the classroom activities in the STEM Learning Modules that were developed during the summer institute and to ensure that they are comfortable using their new skills and materials to help students understand science and engineering concepts. A professional development staff member visits each school once a month. The format of the visits varies, but may include team teaching and/or lesson planning.

Continuous online support is also available to all participating teachers through email, listservs and a project blog. Online resources such as the SLMs, teacher information, reports, photographs, resources from the workshops and other resource material is available on the project website.

### **Evaluation and Preliminary Findings**

A quasi-experimental study using mixed methods was used to assess the program. Specifically, as part of our data, the following data were collected from our experimental group teachers during the 2-week summer institute: (1) pre and post tests, (2) formative assessments (e.g. end of the day evaluation, concept mapping, discussion, and questions), (3) and the STEM Learning Module as their culminating project. In addition, an on going data collection of artifacts (e.g. pictures, informal observations), activities, and reports are being collected and compiled during the classroom visits and consultations. These data sources aim to capture the progression and the development of the teachers' content knowledge and pedagogy that is translated into classroom practices over a period of one year. Comparison group teachers and students were carefully identified and selected in September, 2007. Pre- and post- tests for comparison teachers and pre-tests for students were also given in the same month.

Preliminary findings<sup>15</sup> from the pre and post tests of experimental group teachers, administered at the beginning and the conclusion of the summer institute, indicate that participants significantly increased their content knowledge in specific life science topics and concepts involving the engineering design process. Twenty life science and five engineering questions were selected from available test questions developed and used by the National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Science Study (TIMSS),

and the Museum of Science (MOS) in Boston, MA. The mean score increased by 1.68 points or 6.72 percentage points which was significant. There was increased homogeneity in performance as indicated by a decreased range and standard deviation. See Table 2 for more details regarding the analysis.

**Table 2: Impact on Teacher Content Knowledge in Science and Engineering**

Evaluation N=56	Minimum Score	Maximum Score	Mean	Standard Deviation
Pre-Test	12	24	20.71	2.647
Post-Test	17	25	22.39	1.775
Increase is statistically significant $t(55) = 5.94, p < .0001$				

A study between the experimental and comparison group of teachers indicated a significant difference between the achievements attained by the two groups. The comparison group teachers were selected and matched against the experimental group of teachers based on the school's geographic location, demographics, grade level, and subjects being taught. The same instruments were used to assess the content knowledge of the two groups of teachers. For both the experimental and comparison groups, the instruments were administered twice; two weeks apart. The mean score change of the experimental group increased by 6.72 percentage points from pre to post test while the comparison group of teachers gained only 1.04 percentage points (Table 3). The difference between the number of teachers in each group was due to the following reasons: several teachers were teaching the same group of students therefore only one comparison teacher was needed; several teachers in the experimental group left the program before the beginning of the school year; and technology teachers supporting the classroom teachers in the experimental group did not get comparison teachers.

**Table 3: Analysis of Experimental and Comparison Teachers**

Group	Number of Teachers	Mean Score Change		Standard Error
		Raw Score	Percentage Points	
Experimental	56	+1.68	+6.72	.283
Comparison	27	+.26	+1.04	.305
Difference between the groups is statistically significant $F(1,81) = 9.55, p = .003$				

### Implementation Insights

Two emerging themes have been observed from the analysis of the formative assessments, the STEM Learning Modules, and from the artifacts and records collected during the classroom visits:

- An increase of teacher's content knowledge and transfer of learning from the workshops/training to the classroom and
- An increase in motivation and attitudes towards science and engineering.



## Increase of Teacher Content Knowledge and Transfer of Learning to the Classroom

An increase in teacher content knowledge and transfer of learning from workshops/training to the classroom as shown in the development of the SLMs, workshop evaluations, and classroom visits has been demonstrated. Scientific inquiry and the engineering design process were two of the underlying vehicles that provided the focus and coherence to the topics and concepts in the two-week institute.

**“The inquiry and engineering design process are both eye-openers for me, as far as teaching is concerned.”** – Nonpublic School Teacher, Evaluation Report, August 2007.

For instance, the concept map developed by one group of teachers (Figure 1) showed the connections of the concepts of classification, living things, plants, insects, and the design of hand pollinators. In the classroom, this particular teacher used the *Square of Life* online telecollaborative project to introduce classification to the students. Students learned to identify living and non-living things in their school yard, shared their finding with other participating classes, analyzed and reported their findings. As part of the engineering activity and design challenge, the teachers used the *Engineering is Elementary: The Best of Bugs* module challenge students to use the engineering design process to design hand pollinators (Figure 2).

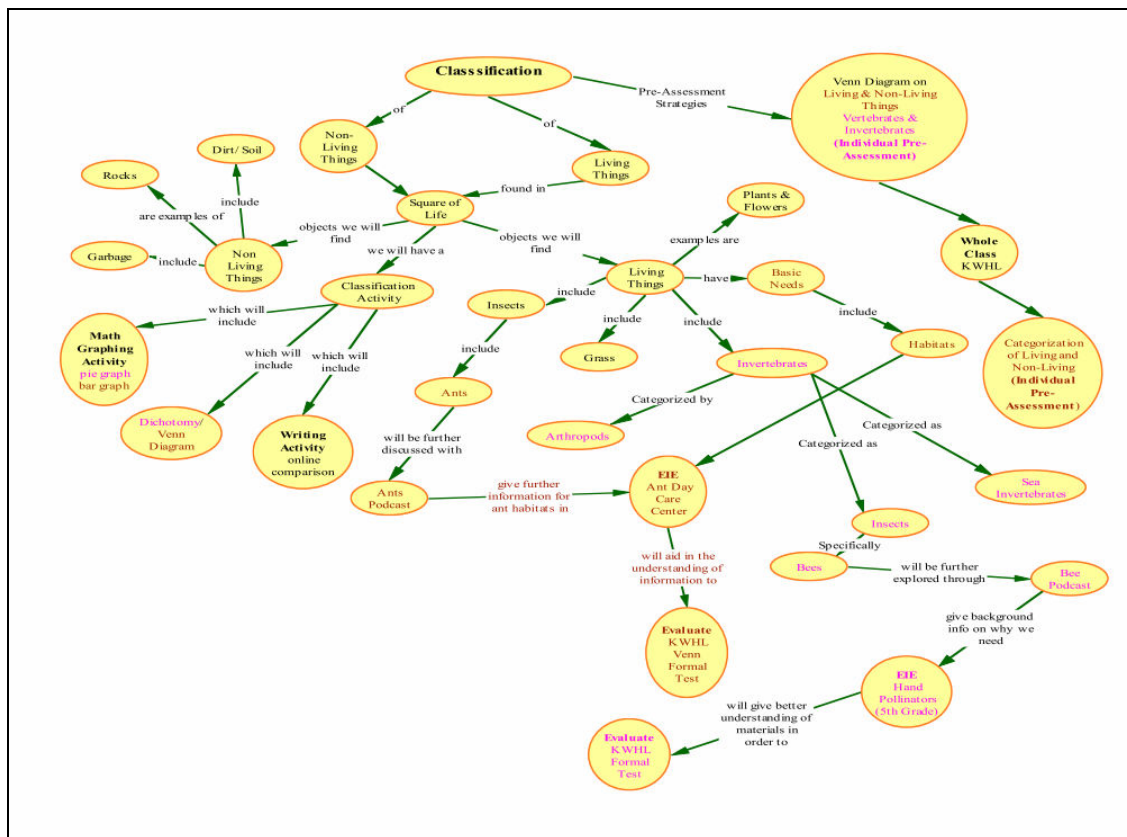


Figure 1: Concept Map



**Figure 2: Students Design and Test Hand Pollinators**

Another example is the “Water and the Environment” follow-up workshop held in October, 2007. The teachers learned the different properties of water, the different environmental factors that affect the environment and various techniques for how to teach these concepts to their students. In the following months, teachers used, adopted, and applied what they learned from the workshop in their classrooms. In one particular case, teachers in one school gathered all the Grades 3-5 students and asked them to work together to build four different watershed-friendly communities. The students worked as environmental scientists and engineers to build these four communities that were on top of the watershed. Students learned how to negotiate, compromise, study, plan, and work with each other and with other communities to preserve the water source and to use the water efficiently. They applied what they learned in science by deciding where to put the school, farm, factory, community, and others in their community with respect to the water source and the other communities (Figure 3).



**Figure 3: Students Build Communities within a Watershed**

### Increase in Motivation and Attitudes Towards Science and Engineering

Teachers’ lack of motivation and anxiety regarding science and engineering was evident on the first day of the summer institute. To meet this challenge of improving their confidence in teaching science and engineering, a variety of activities at different levels of content/instruction and multiple formative assessments were created.

***“This program made me appreciate science and engineering. The Engineering is Elementary (EiE) binder is a wonderful resource and the lessons provided are excellent. I will be utilizing those binders and what I learned during the training to the classroom. I am convinced that my students will have better appreciation of science.”*** – Jersey City Public School Teacher, Evaluation Report, July 2007.

Classroom visits, consultations, and mentoring of teachers are an ongoing effort among the project partners. The classroom visits aim to help the teachers apply what they learn from the workshops and to mentor them in both content and pedagogy in developing their own science and engineering lessons. The teachers and students both benefited from the time and support given by the mentors. Classroom artifacts (e.g. pictures, informal observations), activities, and reports that were collected and compiled during the classroom visits and consultations show that teachers use, develop, and revise what they learned from the workshops and adopt them in their classrooms.

***“On behalf of the students in my fourth grade class, I once again thank you for visiting my class. You truly tap into their creativity, inspire them to think, plan, experiment, and discover many fascinating things that are right under their noses. The most recent activity, entitled ‘Mystery Bag’ proved how a simple, household item can open doors and encourage children to explore. They understand the concept of technology and why human beings have created things to help make life easier. More importantly, the children are acting like engineers. Throughout the course of the day, they often refer to the Engineering Design Process and follow the steps of asking, imagining, planning, creating, and improving.”*** – Fourth Grade Teacher, December 2007.

Another follow-up workshop, “Developing Scientists in Your Classroom,” was held in December, 2007 and used the “study of the worms” to develop the inquiry approach to teaching and learning science. The teachers observed the worms, generated questions about the worms, planned and did investigations using the worms, and reported their findings. Their initial “yucks” turned into enthusiasm for the study of science. A number of teachers soon used the inquiry activity of using the worms to entice their students to learn. The teachers’ initial fear that their students would not like the study of the worms because of the “yuck” factor quickly vanished (Figure 4).



**Figure 4: Students Working with Worms**



## Next Steps

In addition to measuring changes in teacher content knowledge and pedagogy, this project will also evaluate changes in student learning of science topics and processes, technology, and engineering. Pre tests for experimental and comparison groups of students were administered at the start of the school year, September 2007 and post tests will be administered at the end of the school year, June 2008. Student evaluation results for year 1 are anticipated to be available in the summer of 2008.

Year 2 activities for this MSP Project will focus on engaging the same group of teachers in a children's engineering design process developed by a consortium of educators from New Jersey. *Children's Engineering* will provide a framework for helping teachers to identify a variety of real-world problems and the steps necessary to solve these problems in the area of earth science. Teachers will learn to apply the engineering design process to a problem of their own choosing. Teachers will develop a second SLM, not based on an existing EiE module but, rather, on a problem that they identify. The process of learning how to "problem-solve" will provide teachers with a blend of strengthened content and pedagogical expertise. The SLM will incorporate teacher- and district-identified needs of the students and any other needs based on the evaluation of goals from year 1. Professional learning communities will continue to explore content, pedagogical strategies, learning research, and resources to improve student learning.

In year 3, activities will focus on deepening understanding of student learning in physical science and of the engineering design process and problem-solving; expanding repertoires for engaging girls and underrepresented students in STEM; and promoting lasting communities among participants and faculty at partner institutions and organizations. The program will take teachers through increasingly sophisticated approaches to identify problems and formulate solutions, with a focus on entrepreneurial activities. Teachers will be trained on how to implement this process with their students. For students implementing this process in their classrooms, the outcome will be an invention that addresses a real problem they have identified.

This Math-Science Partnership project is one component of Stevens Institute of Technology's initiative known as Engineering Our Future NJ, a statewide initiative that aims to ensure that all students, elementary through high school, experience age-appropriate engineering curricula as a required component of their education. Preliminary evidence from year one indicates that curricula and associated professional development that fosters the application of science and mathematics principles improves both teacher content knowledge and motivation and interest in science and engineering. As the project continues, teacher content knowledge and student achievement in life science, earth science and physical science will be studied.

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