AC 2010-2290: PARTNERSHIP TO IMPROVE STUDENT ACHIEVEMENT IN ENGINEERING AND SCIENCE EDUCATION: LESSONS LEARNED IN YEAR ONE

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Partnership to Improve Student Achievement in Engineering and Science Education: Lessons Learned in Year One

Abstract

Through a state-sponsored Math-Science Partnership (MSP) program, 57 grade 3-5 teachers in six urban districts in N.J. received professional development, classroom support, and mentoring in innovative science and engineering curricula designed to make use of constructivist approaches to teaching and learning. Two universities, a science center, and a teacher education institution collaborated in delivering project services to schools. Through intensive professional development, teachers engaged in science inquiry lessons, learned about and practiced the engineering design process (EDP), and interacted with science and engineering faculty to bolster their science content knowledge in life and environmental sciences. Preliminary findings from the pre and post tests of treatment group teachers indicate that participants significantly increased their content knowledge in specific life science topics and concepts involving the engineering design process. Similarly, analysis of pre and post tests of students who were taught by teachers in the treatment group indicate gains more than two and a half times greater in science and engineering content knowledge than the students of teachers in the comparison group. This paper describes the efforts and findings during the first year of the three-year program.

Introduction

The Partnership to Improve Student Achievement (PISA), a state-sponsored Math-Science Partnership (MSP) program, commenced in July 2007 with 57 grade 3-5 teachers from six urban districts in N.J. Two separate two-week summer institutes were conducted, during which time teachers engaged in science inquiry, learned about and practiced the engineering design process (EDP), visited research labs and interacted with science and engineering faculty and staff from Stevens Institute of Technology to bolster their science content knowledge in life and environmental sciences. The culmination of the summer institute was the creation of a STEM Learning Module (SLM) which teachers implemented in their classrooms during the 2007-08 school year. Summer institute instructors guided teachers in development of the SLMs using the 5E Model (Engage, Explore, Explain, Elaborate, and Evaluate)[1]. The SLMs reflect the science content, engineering skills and approaches, cyber infrastructure curricular tools, and pedagogical strategies that the participants learned during the summer institutes. All SLMs created by participants incorporated: (a) active student learning, (b) team-based approach to teaching, (c) computer-based technological resources in the lesson, (d) the engineering design process, and/or (e) the inquiry approach to teaching and learning science.

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 21st century workforce skills and to apply science and mathematics toward the solution of relevant, real-world problems. Specifically, the goals for year one were to (a) improve participating teachers' content knowledge in life and environmental sciences and technology (information technology and engineering), and (b) improve teachers' pedagogical knowledge in creating and adopting science inquiry and engineering lessons, and (c) improve the content knowledge of students in Grades 3-5 in life and environmental sciences and technology.

Each year of the three-year MSP program focuses on a different science discipline. The first year, which ended in June 2008 focused on life science, environmental science, engineering, and use of computer technology. Subsequent years will focus on earth, space, and physical sciences. Scientific inquiry and the engineering design process provided the focus and coherence to the topics and concepts covered in this program. Science activities in the workshops were based on the notion of scientific inquiry from the National Science Education Standards[2] and the 5E Model (Engage, Explore, Explain, Elaborate, and Evaluate)[1]. The engineering activities provided the hook for participants to learn science. The *Engineering is Elementary (EiE)*[3] curricula were 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.

By the end of the first year of the PISA program, teachers had received in-depth, content specific, pedagogical support, 124 hours of continuous professional development, and frequent (monthly) on-site support (coaching, modeling, curriculum alignment, planning) by project partners. The production of a STEM Learning Module through collaboration and in-depth/topic-oriented professional development promoted teachers' pedagogical content knowledge specifically in STEM areas.

Background

Technological literacy as well as scientific literacy are crucial for students to compete in the global economy of the 21st century[4,5,6]. There is a widening gap in math, science and engineering achievement between American students and those in other developed and developing countries[4]. 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[7]. These results were partially due to teachers lacking the content knowledge, pedagogical knowledge, expertise, and certification to teach the subject and lack of coherence in pre-service and professional development programs offered to teachers[4,7,8,9]. Trends reported by multiple government and private agencies show that there are not enough students in the pipeline today to support the workforce of tomorrow[4,6,7]. By 2005, the number of science and 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[4]. 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[7]. 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[9,10]. These skills are increasingly recognized by business, higher education, and policy leaders as critical for tomorrow's workforce[4,11].

These concerns challenge teachers and policy makers to improve teaching, learning, teacher preparation programs, and professional development programs[7,8,9,12]. 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"[13]. Unfortunately, inequalities in the qualities of instruction and qualifications of teachers and resources result in widely different learning opportunities for different group of students[12]. 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. 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. 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[4,7,8].

The No Child Left Behind (NCLB) Act of 2001, a major landmark reform in education in the U.S., calls for "highly qualified" teachers in every classroom by the end of the 2005-2006 school year. To be highly qualified, a teacher must (a) hold a bachelor's degree, (b) hold a certification to teach in the state of his or her employment, and (c) showed mastery of the subject he or she is teaching. NCLB recognizes that "teachers are one of the most critical factors in how well students achieve"[14]. Unfortunately, a recent report of Margaret Spellings, Secretary of Education, in August of 2006 indicated that despite progress in 50 U.S. states, many states still did not meet the NCLB criteria. A peer review panel formed by the U.S. Department of Education set a six-point protocol to help all the states meet the requirements. Results indicated that only nine states have met the requirements, thirty nine states partially met the requirements, and four states did not meet the requirements[15].

This MSP program was developed to help teachers of Grades 3-5 with little or no science background to gain content knowledge and pedagogy in science and engineering in order to meet the requirements set by the NCLB legislation[14] and to answer the call of the Rising Above the Gathering Storm report[4]. It is the intention of this program to increase the content knowledge of students in science and engineering by bolstering the content knowledge and pedagogy of teachers who are enrolled in this program[16].

Methods

A quasi-experimental study using mixed methods was used to assess the program. Specifically, the following data were collected from our treatment group teachers during the 2-week summer institute: (1) pre and post test, (2) results from formative assessments (e.g. end of the day evaluation, concept mapping, discussion, and questions), (3) and the STEM Learning Module (SLM) as their culminating project. In addition, artifacts (e.g. pictures, informal observations), activities, and reports were 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.

The treatment group included 57 teachers of grades 3-5 from 24 public schools and 2 non-public schools. A comparison group of 33 teachers were selected and matched against the treatment group of teachers based on the school's geographic location, demographics, grade level, and subjects being taught. Many teachers were teaching the same group of students therefore only one comparison teacher was needed; several teachers in the treatment group did not persist in the program for a variety of reasons (e.g. reassignment to a lower or higher grade than the focus of this project); and technology teachers supporting the classroom teachers in the treatment group did not get comparison teachers.

A single instrument was used as the pre- and post-test to assess the content knowledge for both groups of teachers. The questions were selected from the available questions published online by the Trends in International Mathematics and Science Study (TIMSS)[17], the National Assessment of Educational Progress (NAEP)[18], and items developed by the Museum of Science in Boston[3]. The instrument was administered twice; two weeks apart for all teachers. Student pre-tests were administered at the beginning of the 2007-08 school year to 555 students of MSP participants who received professional development as well as to 558 students of teachers who were selected as comparison group teachers. Post-tests were administered to all students at the conclusion of the 2007-08 school year.

Student pre-tests covering topics in life science and engineering were administered at the beginning of the 2007-08 school year to students of MSP participants who received professional development as well as to students of teachers who were selected as comparison group teachers. Post-tests were administered to all students at the conclusion of the 2007-08 school year.

Results

Impact on Teachers

Findings from the pre and post tests of the treatment group teachers, administered at the beginning and the conclusion of the summer institute, indicate that participating teachers significantly increased their content knowledge in specific life science topics and in the engineering design process. The mean score increased by 1.91 points or 7.6 percentage points. Using a paired t-test, this result was found to be statistically significant ($t(56) = 6.11$, $p<.001$). There was increased homogeneity in performance as indicated by a decreased range of scores and a smaller standard deviation. See Table 1 for more details regarding the analysis.

Table 1: Impact on Teacher Content Knowledge in Science and Engineering

Assessment	N	Minimum Score	Maximum Score	Mean	Standard Deviation
Pre-Test	57	12	24	20.47	2.682
Post-Test	56	17	25	22.38	1.805
Increase is statistically significant $t(56) = 6.11$, $p<.001$					

While these results support the conclusion that teacher content knowledge in science and engineering increased as a result of the program, an additional analysis was performed to determine if these results were significantly different than those obtained from a comparison group of teachers. Teachers in the comparison group were selected and matched to the treatment teachers based on the school's geographic location, demographics, grade level, and subjects being taught. 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 and therefore only one comparison teacher was needed; several teachers in the treatment group left the program before the beginning of the school year; and technology teachers supporting the classroom teachers in the treatment group did not get comparison teachers. The same instrument was used to assess the content knowledge of the two groups of teachers. For both the treatment and comparison groups, the instrument was administered twice; two weeks apart.

Table 2: Analysis of Treatment and Comparison Teachers

Group	Number of Teachers	Mean Pre Test Score	Mean Post Test Score	Mean Score Change		Standard Error
				Raw Score	Percentage Points	
Treatment	56	20.47	22.38	+1.91	+7.6	.292
Comparison	33	21.12	21.79	+0.67	+2.7	.330
Difference between the groups is statistically significant $F(1,88) = 5.973$, p=.017						

ANOVA was used to compare the mean score gains for the treatment and comparison teachers. The mean score of the treatment group increased by 7.6 percentage points from pre to post test while the comparison group of teachers gained only 2.7 percentage points on average. This difference was statistically significant ($F(1,88) = 5.973$, p=.017) (Table 2).

Along with the noted increase of teachers' content knowledge, two emerging themes have been observed from the analysis of the formative assessments, the SLM, and from the artifacts and records collected during the classroom visits: (1) Successful transfer of learning from the workshops/training to the classroom and (2) an increase in motivation and attitudes toward science and engineering.

For instance, the concept map developed by one group of teachers 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 objects in their school yard, shared their findings 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.

Another example is the "Water and the Environment" follow-up workshop held during the school year. 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.

Similarly, an increase in teacher motivation and attitudes towards science and engineering was demonstrated during the first year activities. 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.

"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.

Daily evaluations and teacher interviews indicated that participants felt better prepared to teach life science concepts and were confident in their ability to replicate institute activities in their classrooms.

Impact on Students

The MSP PISA project impacted the science achievement of students in Grades 3-5 in six urban school districts in New Jersey. Student pre-tests were administered at the beginning of the 2007-08 school year to 555 students of MSP participants who received professional development as well as to 558 students of teachers who were selected as comparison group teachers. Post-tests were administered to all students at the conclusion of the 2007-08 school year.

Preliminary findings (based on internal analysis) from the gains achieved by students as measured by a difference between pre- and post-test scores indicates that the students of teachers in the treatment group had gains more than two and a half times greater than the students of teachers in the comparison group; a statistically significant difference ($F(1,1112) = 112.9$, $p < .001$). Test score data and analysis details from the ANOVA calculations are shown in Table 3.

Table 3: Analysis of Student Scores, Composite

Group	N	Mean Score		Mean Score Change		Standard Error
		Pre-test	Post-test	Raw Score	Percentage Points	
Treatment	555	8.34	11.59	3.25	16.3	.122
Comparison	558	8.39	9.61	1.22	6.1	.147
Difference in gains (mean score change) is statistically significant $F(1,1112) = 112.9$, $p<.001$						

The assessment used as the pre- and post-test included items related to both science content and the engineering design process. Students in the comparison group likely received no instruction in the engineering design process; therefore, a more valid measure of program impact on student achievement may be achieved by comparing student gains on the science content portion of the assessment alone. The findings indicate that the students of teachers in the treatment group had science achievement gains almost two times greater than the students of teachers in the comparison group. ANOVA was used to determine whether this difference is statistically significant. As shown in Table 4, the difference in gains for science content alone is highly significant ($F(1,1112) = 72.80$, $p<.001$). As would be expected, the difference in gains is somewhat less than that on the entire assessment because treatment group scores on the engineering post-test were significantly higher than on the pre-test.

Table 4: Analysis of Student Scores, Science

Group	N	Mean Score		Mean Score Change		Standard Error
		Pre-test	Post-test	Raw Score	Percentage Points	
Treatment	555	7.11	9.47	2.36	11.8	.119
Comparison	558	7.11	8.11	1.00	6.3	.106
Difference in gains (mean score change) is statistically significant $F(1,1112) = 72.80$, $p<.001$						

Additionally, teachers reported that PISA activities provided opportunities for their students to use critical thinking skills and to do scientific inquiry. In one PISA activity, teachers used live worms to engage students in the study of the characteristics and parts of the worms, their ecological role, and to demonstrate good scientific practices. During the investigations, students were asked (via guided inquiry) to observe, ask questions, analyze their questions, plan their investigations, investigate, gather data, report their data, and analyze the class' data. For instance, one class of grade 4 students asked the following questions after their initial observations: (a) Do worms have heads or tails and if they do, how can we tell the head from the tail? (b) Do worms like it in the dark or bright? (c) How old are the worms, how can we tell?; and (d) How can we tell if a worm is a male or female?

As a class, through the guidance of their teacher, students analyzed each question to see whether the particular question could be investigated during the class period. Based on the class' discussions, the students decided to perform simple investigations to answer the first and second questions (a & b), investigate question (c) on another day because it would take them a longer time to measure the length of each worm and to estimate the number of segments, and the fourth question (d) was assigned for homework because it couldn't be answered by doing a simple classroom investigation but could be answered by reading a book or doing Internet research. While doing the investigations, students had a chance to manipulate variables, understand variables, discuss fair testing, gather data, represent their data in multiple ways (including numbers and graphs), and ask more questions. The students were all engaged in doing their investigations, explained the rationale of their experiments, and defended their data/findings.

Figure 1: Students working with worms and building communities within a watershed

Students were active learners and their motivation was positively affected; they were engaged and excited. One vice principal of partner school reported that many of her troubled students who engaged in PISA-designed activities were motivated and engaged to learn science because of the engineering challenges. She said that she used these engineering challenges to encourage them, who are always in her office, to go back to their classroom.

Teachers reported that students felt comfortable using the engineering design process. In one activity, teachers engaged their students in the engineering design process using *Engineering is Elementary: Water*, *Water Everywhere* that posed a design challenge. Students were asked to help "Salila", who lives in India and encountered problems in the water of the Ganges River, by discussing the possible sources of water pollution (using pictures), investigating the different materials that could be used for water filters, and designing, testing, and redesigning water filters. The students enjoyed the design challenge and took the challenge seriously. Moreover, the teachers said that their students asked more questions about the science behind water and water filtration after they designed and tested their own water filters.

The use of inquiry-based science and of research-based, interdisciplinary, hands-on curricula and instructional strategies for science and engineering for participating teachers has had a significant impact on student learning of life science topics and processes, technology, and engineering. Students have demonstrated increased interest and engagement, and improved critical thinking, scientific inquiry, and teamwork skills as a result of their teachers' participation in the PISA program.

Lessons Learned and Next Steps

Technological literacy as well as scientific literacy are crucial 21st century learning goals for students. For literacy to be achieved in both areas, intensive and ongoing teacher professional development programs and classroom support are needed to foster teacher's content knowledge. The professional development model used in the PISA program was based on the work and calls for improvement presented by Resnick[8] and Borko[9]. The professional development contained multiple levels of instruction (i.e. university level, elementary, etc.), variety of methodology (i.e. lecture, hands-on, field work, etc.), and different levels of discourse (i.e. teacher, peer, and student) to connect theory into classroom practice[12, 16]. The increase in teacher's content knowledge in life science and engineering directly or indirectly promoted an increase in student's content knowledge[16]. Through classroom support visits, artifacts were examined that demonstrated students' motivation to learn science through inquiry and engineering design process. This is similar to the work shown by Lachapelle[3] in Boston and New Jersey.

Project objectives and actions in year 2 have built upon the lessons learned in year 1. We are currently using the same model of professional development used in year 1 with the exception of the science topic, which is earth and space sciences instead of life and environmental sciences, and the notion of inquiry, modified from 5E[1] to model-based inquiry[19]. While working with PISA teachers in year 1, it was apparent that teachers hold different views of inquiry. Teachers' views of inquiry range from hands-on experimentation, use of the scientific method, and hypothesis testing to problem solving. This is problematic since we are using scientific inquiry as one of the vehicles to drive science instruction. This is similar to what Windschitl[20] saw with his teachers and what he called "folk theories" of inquiry. In most cases, students perform basic experimentation in the classroom that is widely promoted in elementary textbooks and that deals with comparing only two variables which is different from how scientists work in a real world. Students devise hypotheses that are merely wild guesses, and that doesn't necessarily promote talking about scientific models[19,20,21]. In addition to measuring the teacher's content knowledge in science in year 2, we are monitoring the teacher's notion of inquiry in the workshop and in the classroom. Our workshop and classroom activities will be based on model-based inquiry and the *Engineering is Elementary* curricula. Instruments include pre and post inquiry surveys and a classroom observation protocol.

As a brief update, findings in year 2 will be published and presented at the 2010 National Conferences of the American Association for Engineering Education (ASEE) and the National Association of Research in Science Teaching (NARST). The PISA paper for ASEE will report on teachers' and students' content knowledge in science and engineering. Specifically, analyses of data in year 2 revealed that: (1) teachers in the treatment group increased their mean score by about 13 percent from pre- to post-test while the comparison group's mean score increased by only 3 percent, (2) students of teachers in the treatment group increased their score by about 27 percent from pre- to post-test, while the comparison group only had 16 percent increase, and (3) Students' post-test scores on science questions were significantly correlated with the number of engineering activities they were exposed to, suggesting that using engineering activities could positively affect science learning[22]. Moreover, the PISA paper for NARST will report on the changes in the teachers' notions of scientific inquiry after attending a year of professional development program[23].

In sum, this Math-Science Partnership project is one component of the Stevens Institute of Technology's initiative known as Engineering Our Future N.J., 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. Findings from year one indicated that intensive teacher professional development improved content knowledge of teachers and students in life science and engineering as well as increased students' motivation to learn science. More work is still needed to improve teachers' content knowledge in other subject areas, promote the use of model-based inquiry in the classroom, improve technological literacy, and show the connection between students' learning in science and engineering. Objectives in year 2 and year 3 of the PISA program will address several needs that are mentioned above.

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