Teacher Professional Development in Elementary Schools: Improving Student Achievement Through Science and Engineering

ABSTRACT

Research-based professional development is needed to help teachers implement science and engineering education in elementary schools and to improve students' understanding of engineering and engineering design process (EDP). This is a challenging task, particularly for teachers who many have little familiarity with either science inquiry or EDP, and who may not have developed the instructional strategies needed to facilitate student inquiry and engagement in EDP. In this paper, we report on the Partnership to Improve Student Achievement (PISA) professional development (PD) program and research study that engaged 56, Grades 3-5 teachers in New Jersey in Year 1 and 43 teachers in Year 2. Teachers participated in a two-week summer workshop, three workshops during the school year, and received monthly classroom support visits, which comprised one year of instructional activities in a three-year professional development program. The study also included 555 students taught by PISA teachers in Year 1, 532 students of PISA teachers in Year 2, and 35 comparison teachers and their students in Years 1 and 2. Analysis of pre- and post-data from Year 1 and Year 2 showed that PISA teachers significantly improved their content knowledge in engineering and science compared to the comparison group. Similarly, post-test scores of students in the treatment group were significantly higher than the post-test scores of students in the comparison group as a result of an intensive PD program. Analysis of teacher classroom implementation survey and student post-test scores revealed that student scores significantly correlated to the number of science and engineering lessons that they were exposed to; student scores on science questions significantly correlated with the number of engineering activities that they did, and students taught by PISA teachers improved their knowledge of engineering and EDP compared to the students in the comparison group. Finally, PISA teachers noted that the EDP promoted 21st century skills such as problem solving, collaboration, working on problems with no set solutions, and critical thinking among students.

Key Words: Elementary Students, In-service Elementary Teachers, Professional Development, Science Inquiry, Engineering Design

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INTRODUCTION

Scientific discovery and technological innovation are critical in reaffirming and strengthening America's role in the world (Committee on Prospering in the Global Economy of the 21st Century, 2007). Under a new initiative called Educate to Innovate, President Obama identified three overarching priorities for science, technology, engineering, and mathematics (STEM) education in the United States. These included increasing the STEM literacy of all students, improving the quality of teaching in the STEM disciplines, and expanding STEM education and career opportunities for underrepresented groups (Prabhu, 2010). To make this happen, exemplary professional development programs are needed to help teachers improve student knowledge in science and engineering, and this must begin in elementary school. This is a challenging task, particularly for teachers who may have little familiarity with science inquiry or the engineering design process (EDP), and who may not have developed the instructional strategies needed to facilitate them.

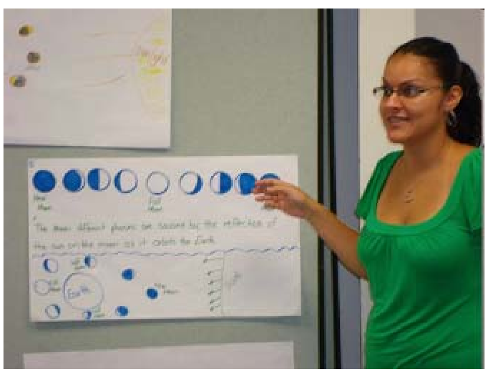
In our Partnership to Improve Student Achievement (PISA) project, we hypothesized that the teacher professional development (PD) program would enhance teacher content knowledge, pedagogy, and student content knowledge. This path of in-service teacher education was described in the literature by Kennedy (1998). We predicted that the instructional lessons modeled in the workshops, which are designed to promote scientific inquiry and the use of the EDP, would enhance teachers' content knowledge and change their classroom practices. Students' content knowledge would in turn improve as a result of these experiences. Our questions were therefore: (1) Did PD translate into classroom practice, defined as implementation of science inquiry and engineering lessons/activities? and (2) Did students in the project classrooms improve their knowledge of specific science topics and understanding of the engineering design process compared to students of teachers in a comparison group?

In the PISA study 56, 3-5 teachers in New Jersey participated in Year 1 and 43 teachers participated in Year 2. In addition, 35 teachers were recruited as matched comparison teachers. PISA teachers participated in a two-week summer institute, three full-day workshops during the school year, and received monthly classroom support visits. Each year the program focused on a different science discipline with associated engineering and technology content. Year 1 was devoted to life and environmental sciences and Year 2, to earth and space sciences. Science lessons were developed using the science inquiry framework (National Research Council, 2000) and constructivist approach to learning (Driver & Bell, 1986). We define science inquiry teaching as a form of inquiry that emphasizes the role of models in scientific practice, in particular, the use of models to build, revise and argue about scientific knowledge, which cultivates the understanding of the nature of science. Model-based science inquiry is an instructional approach in which learners engage in scientific inquiry that focuses on the creation, evaluation, and revision of scientific models used to understand, explain, test, and/or predict parts or characteristics of the natural world (Lehrer & Schauble, 2006; Schwarz, 2009; Windschitl, 2008). In engineering, the EDP involved asking questions, brainstorming solutions, planning, investigating, creating, and revising products (Cunningham, 2009).

Model-Based Science Inquiry Engineering Design Process

Figure 1: Science Inquiry and EDP Frameworks

Sample science lessons included *Human Genetics* tele-collaborative project, *Water and the Environment*, *Phases of the Moon*, and *Reasons for Seasons.* Sample *Engineering is Elementary* modules (developed by the Museum of Science, Boston) included the *Sticky Situation*, which included learning about different earth materials and designing their own walls and *Catching the Wind*, where they studied weather and designed their own windmills.



Phases of the Moon Lesson Designing Windmills

Figure 2: Science Inquiry and Engineering Design Lessons

Classroom support visits were another component of the program intended to ensure that teachers were successful in classroom implementation of what they learned over the summer. Visits were also used to document and assess the needs of teachers and students. Three PD sessions conducted during the school year (two face-to-face and one online) expanded and reinforced the science content knowledge that teachers learned during the summer institute.

PISA aims to address the challenges presented by the Committee on K-12 Engineering Education[2] which recommends: (1) the development and implementation of research-based engineering curricula in elementary schools; (2) funding research studies to determine how science inquiry is connected to engineering design; (3) increasing numbers of PD for elementary teachers in STEM education; and (4) outreach to girls and minority students.

BACKGROUND

Following science education reforms in the 1980s and 1990s (National Commission for Excellence in Education, 1983; National Academy of Sciences and National Academy of Engineering, 1982; American Association for the Advancement of Science, 1993), the National Science Teachers' Association (NSTA) published a set of national science education standards that included standards for the preparation and continuing education of teachers (National Research Council, 1996). The science teaching standards describe what teachers of science at all grade levels should know and be able to do, which is beyond teaching students recall of factual knowledge and honing skills. Specifically, teachers of science are asked to plan and implement inquiry-based science, facilitate student learning, develop learning environment that is conducive to learn science, create communities of science learners, and develop school science program. At the same time, the National Academy of Engineering urged policy makers and educators to promote engineering habits of mind and EDP in K-12 classrooms (Katesi, Pearson, & Feder, 2009). Unfortunately, inequalities in instruction and qualifications of teachers and resources result in widely different learning opportunities for different groups of students (Duschl, Schweingruber, & Shouse, eds., 2007). Most educators teaching engineering as part of the K-12 curriculum lack the knowledge of what engineering is and how they might teach the subject (Cunningham, C. et. al., 2007). At the same time, most teachers attend only a few hours of PD programs, and most programs available to teachers lack the content, continuity, and depth to make meaningful changes in their content knowledge and teaching behaviors (Clewell, Campbell, & Perlman, 2004).

In this study we hypothesized that the teacher PD program would enhance teacher content knowledge, pedagogy, and student content knowledge as described in the literature by Kennedy (1998). We hypothesized that through the instructional lessons in the workshops, which are designed to promote scientific inquiry and the engineering design process, teachers' content knowledge and classroom practices will be enhanced. Students' content knowledge, in turn, will indirectly improve as a result of these experiences.

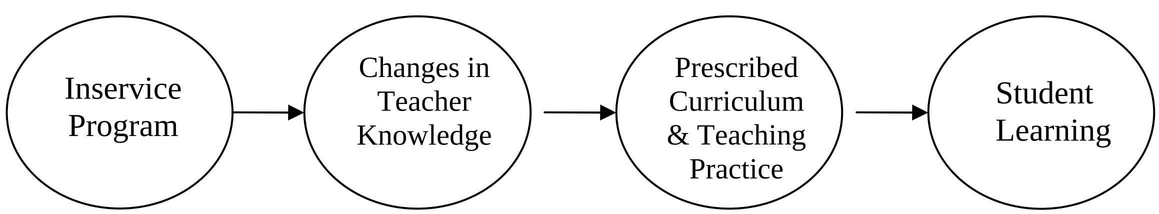


Figure 3: A Path of Teacher Professional Development Program

In this next section, we will present a brief review of the literature that connects the PD program to students' learning. Specifically, the review will illustrate the different features of the program that contribute to teacher content knowledge, classroom enactment, and student content knowledge.

Constructivist approach to learning improves teacher content and pedagogical content knowledge. Ingvarson, Meiers, and Beavis (2005) conducted a survey study that impacted 3,250 teachers who participated in 80 individual PD studies. The review of research studies aimed to identify exemplary models and characteristics of effective PD programs. Findings suggested that the program's content has the most impact on teachers' knowledge. Follow-up workshops also contributed to knowledge gain. In terms of factors that influence teachers' classroom practices, programs that provide many opportunities for active learning and reflection on practice top the list. Finally, when looking at impact on knowledge and practice together, the significance of a professional community became apparent.

Middle school teachers' confidence in teaching engineering design increased after participating in hands-on engineering workshop. Hynes and dos Santos (2007) designed a PD study to prepare 13 middle school teachers in Massachusetts to teach an afterschool engineering/technology robotics unit. The majority of the teachers in the study did not have any formal training in teaching engineering/technology before joining the program. Research findings suggested that the two-week PD was successful in improving teachers' confidence in their knowledge and in teaching engineering principles. Teachers benefited from the program by engaging in multiple hands-on opportunities with the materials, practicing teaching the engineering lessons in a safe environment afforded by the program, and by learning from other teachers.

Elementary school teachers' views of the nature of engineering somewhat improved after participating in engineering PD. Karatas and Bodner (2009) studied ten K-5 teachers to gather their views about engineering/engineering design and distinguish engineering from science. Analysis of interview data showed teachers' positive attitudes towards engineering, but their knowledge of the nature of engineering was mostly limited to what they have experienced through popular culture. Teachers' views of the nature of engineering were influenced by personal relationships or contacts they have had with relatives or friends who are engineers. Moreover, their perception was that engineering was a problem-solving activity process of inventing or creating innovative products. However, teachers did not differentiate engineering from science. Few teachers even thought that engineering was part of (the same domain as) science.

Teacher professional development programs improve student achievement. A study conducted by Fishman, Marx, Best, and Tal (2003) included 40 teachers teaching sixth, seventh, and eighth grade students in 14 urban schools in Detroit, Michigan. Teachers learned project-based science through inquiry pedagogy, which is in line with the constructivist notion of learning. Analysis of pre- and post- assessment, surveys, focus-group discussions, and classroom observations showed positive impact on teachers' knowledge, beliefs about teaching, and classroom enactment. Students' post-test scores also increased after participating in the curriculum projects.

Teacher implementation of engineering lessons improved 85, Grades 3-5 students' perceptions of engineering, the EDP, and the work of engineers. Mena, Capobianco, and Diefes-Dux (2009) worked collaboratively with elementary teachers to create engineering learning activities for students. Based on analysis of pre- and post- administration of the "Draw an Engineer Task" and semi-structured interviews, students' perceptions and knowledge of engineering and the EDP improved by students' providing accurate and discrete examples of different types of engineers, demonstrating understanding of the EDP, acknowledging the work of engineers in helping people and the environment, and recognizing the different types of work that engineers do.

Disciplined inquiry in science and engineering promoted sophisticated, mechanistic reasoning about mechanics of linkages and levers among elementary students. In the study of Bolger, Kobiela, Weinberg, and Lehrer (2009) with nine children in Grades 2 and 5, an analysis of flexible interview showed that children who gave attention to relations between input and output seemed better able to predict mechanism and motion. All children demonstrated at least some elements of mechanistic thinking, but many lacked coordination of multiple elements.

In this brief review, we described the different features of PD that influenced teachers' and students' content knowledge. In our PISA program, we provided a two-week summer institute and three follow-up workshops over one year of a three-year program. These were part of 124 hours of intensive PD aimed at providing teachers with an increased understanding of targeted science and engineering concepts through active learning, specifically, through science inquiry, engineering design, and reflection. We hypothesized improvements in PISA teachers' content knowledge and implementation of engineering and science lessons similar to what Ingvarson, Meiers, and Beavis (2005) found in their study. Given the findings of Hynes and dos Santos (2007) and Karatas and Bodner (2009), we predicted that teachers' confidence in teaching engineering design and their views about the nature of engineering in the classroom would improve after engaging in engineering design activities. In turn, as Mena, Capobianco, and Diefes-Dux (2009) and Bolger, Kobiela, Weinberg, and Lehrer (2009) found, elementary students' perceptions of engineering, the EDP, the work of engineers, and mechanistic reasoning abilities would increase as teachers implemented what they learned from the program. In contrast with Hynes and dos Santos (2007), we integrated the engineering design process in teaching science and provided monthly classroom visits to help teachers implement the program.

METHODS

The first and second PISA institutes were held in the summer of 2007 and 2008. The participating teachers included classroom teachers, inclusion teachers, special education teachers, and a computer technology teacher. Content-related pre- and post-tests, which included questions on the science content areas covered in all classrooms across the state in each grade year, were administered to both teachers and students at the beginning and end of the year, providing data from 56 PISA teachers and 35 comparison teachers and their students (555 students of PISA teachers and 558 students in the comparison group) in Year 1 and from 43 PISA teachers and 35 comparison teachers and their students (532 in each group) in Year 2. During the school year, some teachers left the program, while others did not return both tests.

The following table shows the total number of matched-tests for both years for students and teachers.

Table 1: Number of teachers and students who returned both pre- and post- tests.

	Teachers		Students	
	PISA	Comparison	PISA	Comparison
Year 1	56	35	555	558
Year 2	37	33	532	532

Pre- and post-tests questions were selected from the available questions published online by the Trends in International Mathematics and Science Study (TIMSS), the National Assessment of Educational Progress (NAEP), Misconception Oriented Standards-based Assessment Resources for Teachers (MOSART), and items developed by the Museum of Science in Boston. The instrument was administered twice, one at the beginning of the school year and another at the end of the school year, except for PISA teachers who took their pre-tests before the summer institutes.

In addition to the pre- and post- tests, the PISA group teachers were also asked to complete an end-of-year survey about their implementation of project activities during the year. Thirty-four teachers in Year 1 and 35 teachers in Year 2 replied to this survey.

FINDINGS

Teachers' Pre- and Post- Tests Results

In both years, the PISA group teachers showed a significant increase in their test scores. In year 1 the mean scores of PISA teachers increased from 20.23 to 22.16 points. The increase was statistically significant $t(55)=-6.005$, $p<.01$.

Table 2: Year 1 Teacher Pre- and Post- Test Results

	Mean	N	Std. Deviation	Std. Error Mean
Teacher Score Pre-test	20.23	56	3.039	.406
Teacher Score Post-test	22.16	56	1.886	.252

For year 2 the mean scores increased from 16.11 to 18.27 points and were statistically significant [$t(36)=-3.991$, $p<.01$].

Table 3: Year 2 Teacher Pre- and Post- Test Results

	Mean	N	Std. Deviation	Std. Error Mean
Teacher Score Pre-test	16.11	37	2.706	.445
Teacher Score Post-test	18.27	37	3.297	.542

The PISA teachers also performed significantly better than the teachers in the comparison group in year 1 [$F(1,88)=11.49$, $p<0.01$] as well as in Year 2 [$F(1,67)=8.846$, $p<0.01$]. This suggests that the professional development enhanced the teachers' content knowledge.

Similarly, in both years students of the PISA group teachers performed significantly better on the post-tests than the students of the comparison group teachers. In Year 1 the mean score of PISA students was 11.59 compared to 9.61 for comparison group students. ANCOVA was performed to see if the increase was significant when the pre-test scores were held constant. The test showed that the difference in the two groups was significant, [$F(1,1110)=132.931$, $p<0.01$] when their pre-test scores were held constant. Year 2 showed similar results with PISA students' post test mean score at 11.68 and comparison group students' mean score at 10.49. An analysis of covariance (ANCOVA) was used in order to control for differences in pre-test scores. Before students' pre-test scores were held constant (in ANCOVA), the treatment group had higher post-test scores ($M=11.68$, $SD=4.02$) than the comparison group ($M=10.49$, $SD=3.19$). After students' pre-test scores were held constant statistically, the treatment students still had higher post-test scores than the comparison students. Additionally, the interaction effect between the students' pre-test scores and group variable (PISA or comparison) was significant [$F(1,1060)=6.037$, $p=.014<.05$], showing that the treatment had a greater positive impact on those students who had better pre-test scores.

In short, at the end of the school year, the PISA students were better than the comparison group students in specific science topics and EDP as assessed by pre-post tests. In addition, by Year 2, there was a statistically significant correlation between teacher post-test scores and student post-test scores for the (project) group but not the comparison group, suggesting the PD had an effect on student outcomes by enhancing teacher content knowledge and classroom practice.

PISA Teachers' Classroom Implementation of Engineering Activities and Implications to Science Learning

In addition to the pre- and post- tests, 34 teachers in Year 1 and 35 teachers in Year 2 replied to an end-of-year survey that asked about their implementation of activities they learned in their lessons during the year. There were 29 science and three engineering activities in Year 1 and 21 science and seven engineering activities in Year 2. The average number of activities implemented in Year 1 was nine and the average in Year 2 was 11. Analysis of the Year 2 data showed that post-test scores for the students of these teachers were significantly correlated with the number of activities they were exposed to ($p<0.01$). However, students did not need to be exposed to all the activities, or even most of the activities, but only to about half (12) in order to see this improvement.

One of the most important findings was that in both years, student post-test scores on science questions were significantly correlated ($p<0.01$) with the number of engineering activities they had been exposed to, suggesting that adding engineering activities to the science classroom can positively affect science learning.

About 80 percent of the teachers conducted two or more Engineering is Elementary (EIE) activities in their classroom in both years. In addition, the teachers were enthusiastic about incorporating the engineering design process (EDP) into their lessons. They felt that these activities had helped students structure their problem-solving, had helped them learn to work in groups, and had helped them work on problems with no set solutions. Others shared that the engineering design process fostered critical thinking skills. To quote from a teacher's comment:

"The engineering design lessons are the ones that stood out each and every year. I think the fact that they are able to problem solve (even as a group, which is a feat for students) and create/build something drives home the lesson. This creates and answers the ideas they have in their heads through hand on/visual method."

In addition, two teachers in Year 2 also commented that their students transferred the engineering process steps they learned into other activities.

When asked about the challenges faced while incorporating these lessons, most teachers stated time constraints as a major factor when implementing a particular lesson. The teachers were also asked what prevented them from using more activities. Lack of time, partly due to the demands of test preparation, was the major factor; but some also had difficulty fitting the activities into the existing curriculum.

In an attempt to see if the PISA students did better on some of the post-test questions than the comparison students and if this could be attributed to the PISA activities, in Year 2 we looked at the post-test questions individually. There were a total of 23 questions on the post-test. For each question we counted how many students answered that particular question correctly.

For 12 out of the 23 questions, the number of PISA students who got the answers correct was five percent or more above the number of comparison students who got that question correct. This was particularly the case for the third grade students, suggesting that the activities had a greater impact on students at this grade level than in the higher grade levels (n=532). Only ten questions out of 23 were answered correctly by 50 percent or more students in the PISA group (n=532) while eight questions were answered correctly by 50 percent or more students in the comparison group. In Year 1 between 35 percent and 75 percent students in the PISA group answered the engineering related questions correctly. Considerably more students in the PISA group answered the engineering career question correctly (36.5% in PISA vs. 5.56% in comparison group). In Year 2, between 30 percent and 45 percent of the students in the PISA group got the engineering process questions correct, more than the students who got those questions correct in the comparison group. The following table shows the percentage of students (out of total in that group) who got the engineering related questions correct.

Percentage of students who answered the post-test questions correctly

Table 4: Year 1 Student Post-Test Results

Q#	Question Type	% Comparison students (n=558)	% PISA students (n=555)	Difference
17	Engineering Career	5.56	36.50	26.02
18	Engineering Design Process	49.82	68.35	26.80
19	Engineering Design Process	59.32	74.17	26.02
20	Engineering Design Process	35.48	49.32	16.31

Table 5: Year 2 Student Post-Test Results

Q#	Related PISA activities	% Comparison students (n=532)	% PISA students (n=532)	Difference
20	EiE- A Sticky Situation-Designing Walls	21.99	32.14	10.15
23	EiE- A Sticky Situation-Designing Walls	28.57	37.97	9.40
22	EiE- A Sticky Situation-Designing Walls	34.21	42.67	8.46
21	EiE- Catching the Wind: Designing Windmills	41.73	47.74	6.02

CONCLUSION

The purpose of this study was to examine the PD program in terms of its contributions to teachers' content knowledge, teachers' classroom implementation of PISA activities, students' content knowledge in science and engineering, and students' understanding of the EDP. We report on Year 1 and Year 2 of the program designed to help teachers implement science and engineering lessons in elementary classrooms in response to the challenges presented by the Committee on K-12 Engineering Education (2009). We chose a PD model described in the literature by Kennedy (1998). This path or model targets an improvement in students' content knowledge through changes in teachers' knowledge and teaching practices. Based on our analysis of pre- and post- tests, PISA teachers showed significant increase in their test scores in both years. Moreover, PISA teachers performed significantly better than the teachers in the comparison group. These findings were similar to the reviews of Ingvarson, Meiers, and Beavis (2005) and findings that showed improvements in teachers' knowledge as a result of intensive professional development programs.

Similarly, students of PISA teachers performed better than the comparison group students in specific science topics and EDP based on the pre- and post- tests in Years 1 and 2. Moreover, there was a strong indication that suggests that the PD program had an affect on students' post test scores through the enhancement of teacher content knowledge and classroom practice. Specifically, analysis students' post-test scores in Year 2 revealed that scores significantly correlated to the number of science and engineering lessons to which they were exposed. Moreover, data analysis of students' scores in both years indicated that student post-test scores on science questions significantly correlated with the number of engineering activities to which they were exposed. These findings were reflective of the reviews of research conducted by Fishman, Marx, Best, and Tal (2003) and Mena, Capobianco, and Diefes-Dux (2009), which reported contributions of the teacher PD programs to student achievement, students' perceptions of engineering, and understanding of the EDP.

Further analysis of students' test scores and teacher implementation survey revealed that PISA teachers felt that the EDP helped their structure and problem solving, helped them learn to work in groups, to work on problems with no set solutions, and critical thinking skills. Moreover, item analysis of students' post-test engineering questions showed that considerably more students in the PISA group answered the EDP questions correctly compared to those students in the comparison group. In other words, students taught by PISA teachers improved their knowledge of engineering and engineering design compared to the students in the comparison group. We believe that our findings further support the PD model (Kennedy, 1998) by bolstering students' content knowledge in science and engineering through an increase in teachers' content knowledge and teachers' implementation of engineering and science lessons in elementary classrooms. Our future work includes looking at the data of the PISA Year 3 program, at the teachers' content knowledge, students' content knowledge, and teacher development and implementation of physical science and engineering lessons.

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