Abstract Title:
Teacher Professional Development Programs in Grades 3-8: Promoting Teachers' and Students' Content Knowledge in Science and Engineering

MSP Project Name:
Partnership to Improve Student Achievement in Physical Science: Integrating STEM Approaches ($PISA^2$)

Author(s):
Augusto Macalalag Jr., Devayani Tirthali, Elisabeth McGrath, Mercedes McKay, and Susan Lowes

Presenter(s):
Elisabeth McGrath and Augusto Macalalag, Jr.

120 word summary:

This presentation will examine the components and research findings from the USED NJ MSP project's PD program, which promoted teachers' content knowledge and teaching practices as well as students' content knowledge and 21st century skills in the context of science and engineering. In 2009-2010, 46 elementary teachers attended a two-week summer institute, three school-year PD days, and received monthly classroom visits. Results indicated that teachers and students significantly increased their content knowledge in science and engineering compared to the comparison group; teacher post-test scores were a significant predictor of student science learning as were the number of program lessons taught and the number of engineering lessons taught. These research findings led to the development of the NSF MSP PD program.

Section 1: **Questions for dialogue at the MSP LNC**

This paper will describe the links between the professional development program for elementary teachers and data on student achievement. We describe student achievement as an increase in students' content knowledge in science and engineering and development of their 21^{st} century skills (e.g. collaboration, communication, creativity, critical thinking, etc.) as a result of intensive professional development (PD) program for their teachers.

Key components of the NSF-sponsored $PISA^2$ (Partnership to Improve Student Achievement in Physical Science: Integrating STEM Approaches) program are founded upon activities and research findings from the USED-sponsored NJ MSP program, *Partnership to Improve Student Achievement (PISA*). PISA was a three-year, USED-sponsored Math Science Partnership program (2007-2010) which worked with a single cohort of Grade 3-5 teachers from six northern New Jersey districts to improve their content knowledge and increase student achievement in: Year 1-life and environmental science; Year 2-earth and space science; and Year 3-physical science. While the science content focus changed each year, the program framework, particularly the professional development model, remained essentially the same in Years 1 through 3.

In the 2009-2010 school year, 46 Grade 3-5 teachers participated in a two-week, 80-hour summer institute with three PD days during the school year, and monthly classroom support visits (coaching, modeling, curriculum alignment, and planning) as part of the PISA program.

These 46 treatment teachers affected 796 Grade 3-5 students. A comparison group of 38 teachers with 769 students was selected and matched against the treatment group based on the schools' geographic location, demographics, grade level, and subjects taught by the teacher.

During the two-week summer institute, teachers learned physical science content based on 26 science and engineering lessons presented by engineering and teacher education college faculty and instructors. Science lessons were developed using constructivist approach to learning – scientific inquiry and the engineering design process (EDP). Sample science lessons included investigating static electricity, exploring light bulbs and batteries, describing motions of different colored bubble tubes using diagrams and graphs, and measuring forces. Over the summer, teachers also engaged in two Engineering is Elementary (EiE) modules developed by the Museum of Science, Boston, to learn the EDP. The first module was the Alarming Idea in which they designed an alarm circuit. This engineering lesson highlighted the science concepts of electricity, circuits, and energy. The second module was To Get to the Other Side in which they studied different kinds of forces, experimented on different types of bridges, and designed and tested their own bridge.

Figure 1

Teachers testing a bridge　　Students constructing a circuit

In this paper, we will present findings based on our research questions from the PISA program:

(1) Does the PD enhance the teachers' content knowledge in targeted science and engineering topics?
(2) Does the PD result in improved classroom practice, defined as implementation of science inquiry and the EDP?
(3) Will the treatment group of students improve their content knowledge in physical science topics and engineering after one year of an intensive teacher PD program?

Data for this paper include *pre and posttests* (administered to teachers and students in both treatment and comparison groups) and the *lesson implementation survey* (collected from teachers in the third year of the three-year program).

Research findings from the PISA program provided a foundation for the development of the NSF *Partnership to Improve Student Achievement in Physical Science: Integrating STEM Approaches (*PISA^2) project, which commenced on June 1, 2010. In five years, over 400 Grade 3-8 teachers from 12 school districts will participate in 15-credit hours of graduate coursework or related professional development, as well as two school-year workshops and monthly classroom support visits, to strengthen their science content knowledge and classroom practice in physical and earth sciences with emphasis on sustainability and global resources awareness. In addition, teachers will improve their understanding of how students learn STEM subjects, their use of science inquiry and engineering design, and their ability to facilitate student learning of 21st century skills, such as innovation and creativity, problem solving, and teamwork. School and district administrators will benefit from leadership training and strategic planning efforts to chart a course for strengthening STEM programs in their districts. Finally, the evaluation and research questions in PISA^2 focus on the contributions of a PD program utilizing scientific inquiry and the EDP to 1) *increase teachers' content knowledge* of science and engineering; 2) *improve their attitudes and beliefs about teaching science*; 3) *affect students' content knowledge of science and engineering*; and 4) *enhance students' learning of 21st century skills (such as innovation, creativity, and problem-solving).*

Table 1 (Summary)

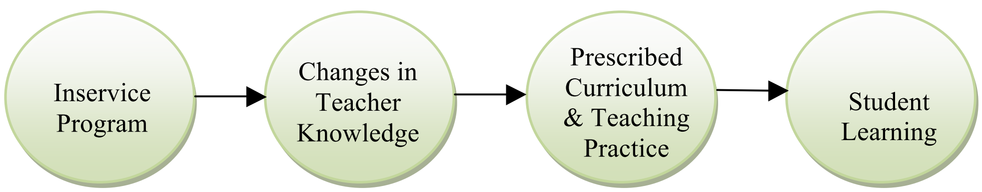
Key Features	**PISA**	**PISA^2**
Funding Agency	USED MSP	NSF MSP
Funding Years	2007-2010	2010-2015
Participants	50 Teachers ~ 700 Grade 3-5 Students	400 Teachers ~ 6,000 Grade 3-8 Students
Partner Schools	21 schools in Northern NJ	40 schools in NJ
Research Studies	Quasi-experimental	Quasi-experimental
Components of the PD program	▪ 80-hour summer institute ▪ three PD days (school year) ▪ monthly classroom support visits ▪ 124 hours total PD hours	▪ 15-credit hours of graduate coursework ▪ two PD days (school year) ▪ monthly classroom support visits
Goals	▪ improve teachers' content knowledge & pedagogical content knowledge in science & engineering ▪ improve students' content knowledge in science and & engineering ▪ develop students' 21st century skills	▪ improve teachers' content knowledge & pedagogical content knowledge in science & engineering ▪ foster improved teacher attitudes & beliefs towards teaching science & engineering ▪ improve students' content knowledge in science and & engineering ▪ develop students' 21st century skills ▪ foster students' positive attitudes & beliefs towards science & engineering subjects/careers ▪ promote institutionalization & sustainability

Section 2: **Conceptual framework**

Exemplary professional development (PD) for teachers can have a positive impact on students' learning and the classroom environment. Specifically, Blank and de las Alas (2009) found successful PD experiences for math teachers contributed to an increase in teachers' subject knowledge, pedagogy, and students' content knowledge. However, teacher PD that focuses on integrating science and engineering in elementary schools is still in its infancy. The engineering component of science, technology, engineering, and mathematics (STEM) education has been overlooked in K-12 teacher education for many years (National Academy of Engineering, 2009). Scientific inquiry and the EDP promote "habits of mind" such as critical thinking, problem solving, communication, collaboration, creativity, and innovation, which are essential skills to be productive citizens. Other potential benefits of engineering in K-12 education include improved learning and achievement in science and mathematics, engagement in the EDP, awareness of engineering as a career, and increased technological literacy (NAE, 2009).

In our study, we hypothesized that the teacher 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 hypothesized that through the instructional lessons in the workshops, which were designed to promote scientific inquiry and the EDP, teachers' content knowledge and classroom practices would be enhanced. As a result of these experiences, students' content knowledge, in turn, would indirectly improve.

Figure 2



Ingvarson, Meiers, and Beavis (2005) conducted a survey with 3,250 teachers who participated in 80 individual PD studies. Their findings suggested that *the program's content has the most impact on teachers' knowledge*. Follow-up workshops also contribute to knowledge gains. In terms of factors that influence teachers' classroom practices, programs that provide many opportunities for active learning and reflection on practice top the list. In another study that examined nine studies in terms of the effect of teacher PD on student achievement in science, mathematics, and language arts, Yoon, Duncan, Lee, Scarloss, & Shapley (2007) found *a* relationship between the number of PD hours for teachers and student achievement. Specifically, *studies that had more than 14 hours of PD showed a positive and significant effect on student achievement*. The three studies that involved the least amount of PD (5-14 hours total) showed no statistically significant effects on student achievement.

In looking at the PD that focused on preparing middle school teachers to implement engineering/ technology education in the classroom, Hynes and dos Santos (2007) found that *the two-week PD was successful in improving teachers' confidence in their knowledge and in teaching engineering principles*. Specifically, teachers benefited from the program by engaging in multiple hands-on opportunities with the materials by practicing teaching the engineering lessons in a safe environment afforded by the program, and by learning from other teachers. Our brief review described the different features of PD that influenced teacher and student achievement.

In this brief review, we described the different features of PD that influenced teacher and student 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 provide teachers with increased understanding of targeted science and engineering concepts through active learning, specifically through science inquiry, engineering design, and reflection. We hypothesized that treatment teachers' content knowledge would increase (*based on the program's content, numerous opportunities for active learning and reflection, and number of PD hours)* similar to what Ingvarson et al., (2005) and Yoon et al., (2007) found in their reviews. In contrast with Hynes and dos Santos (2007), we integrated the EDP into the teaching of science and provided monthly classroom visits (in addition to two-week PD) to help teachers implement the engineering and technology lessons of the program.

In our PISA^2 project, we hypothesize that the components of our intensive professional development program (consisting of five graduate courses or equivalent to deepen teachers conceptual knowledge of physical and earth sciences; problem-based learning methodology [the EDP]; and classroom support visits) will lead to improved teacher content knowledge and increased attitudes and beliefs in teaching science. We also hypothesize that this PD experience will lead to improved student learning in science and in student attainment of 21st century skills of creativity/innovation and problem solving.

Section 3: **Explanatory framework**

Evaluation and/or research design, data collection and analysis

Teachers

I think the most difficult thing for students is learning science concepts from a book. The PISA activities are based upon hands-on activities, which really get the students engaged, resulting in a much better understanding of the science concept.

—3rd grade teacher

Forty-seven teachers attended the PISA workshops held in summer 2009 (21 in July and 26 in August). One teacher left the project at the beginning of the 2009 school year when she moved grade levels. With the exception of seven non-lead teachers (co-teachers and a technology teacher), the remaining 39 lead PISA teachers were matched with 39 comparison teachers based on the grade level they taught.

The teachers were distributed relatively evenly across grades, although more taught 3rd grade:

Table 2

Grades taught (as of Fall 2010)	# of teachers	Percent
3rd grade	16	41%
4th grade	12	31%
5th grade	11	28%
Total	**39**	**100%**

Almost all were experienced teachers:

Table 3

Years teaching (as of Fall 2010)	# of teachers	Percent
New (1-2 years)	2	4%
Somewhat experienced (3-5 years)	5	11%
Experienced (6-10 years)	16	35%
Veteran (11 years and up)	23	50%
Total	**46**	**100%**

Instruments

Two instruments were developed to measure changes in teachers' content knowledge and implementation of PISA activities. The first instrument was the pre and posttest to assess the content knowledge of both groups of teachers in physical science topics and engineering. There were 25 questions – 20 relating to science and science-related mathematics and five relating to engineering. Science questions were selected from the available 8^{th} or 12^{th} grade level questions published online by the Trends in International Mathematics and Science Study (TIMSS), Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART), Praxis Test Prep Materials, and A Private Universe Project. Engineering questions were selected from the *EiE* evaluation questions developed by the Museum of Science, Boston. Pretests were given to treatment teachers on the first day of the summer workshop and administered individually to comparison teachers in September 2009. Both groups of teachers received their posttest in May 2010.

The second instrument was a survey to capture the lessons that teachers in the treatment group implemented and considered had worked well during the school year. The lesson implementation survey was administered on the last month of school year (May 2010). This survey asked teachers to: 1) indicate the lessons they had used in their class, 2) list activities that had worked well and they intended to repeat, 3) describe the changes they would make, and 4) enumerate the challenges they encountered in teaching the lessons.

Results: Teachers' Pre and Posttests

Based on the analysis of teacher pre and posttests, the treatment teachers had a statistically significant increase in their test scores, from a pretest mean of 14.09 points to a posttest mean of 16.52 points ($t(45)= -3.453$, $p<.01$) – a 17 percent increase. The mean posttest score of the comparison teachers increased by 7 percent; but in this case, the difference was not statistically significant [$t(37) = -1.386$, $p>.05$]. In order to compare the performance of the treatment and comparison teachers, it was necessary to adjust for the differences in the pretest scores between the two groups. Using these scores as a covariate, the analysis of covariance (ANCOVA) showed that the teachers' pretest scores were a significant predictor of their posttest scores [$F(1,80) = 18.309$, $p<.01$]. The ANCOVA, without the interaction component (Group*TeacherScorePre), showed that the difference in posttest scores between the two groups was significant [$F(1,81) = 12.498$, $p<.01$] when the pretest scores were statistically held constant. *In other words, the treatment teachers' posttest scores improved significantly more than the comparison teachers' posttest scores, even after their slightly higher pretest scores were taken into account.*

Results: Teachers' Surveys

The Physical Science part of the PISA program was very, very beneficial. I did not like teaching this part of science because I didn't have a thorough understanding of the topics myself, but also because I didn't understand the activities and labs that I was finding to use with the students. After this past year, I feel much more confident and comfortable teaching the material.

—3rd grade teacher

Twenty-six science and engineering activities were introduced to the teachers during the PISA workshops. The greatest number of activities used by any teacher was 21, or 81 percent of the total number of activities. Of the 26 activities, 21 were science and five were engineering. The 44 teachers who returned the survey responded to a series of questions about the activities they had used. Teachers implemented an average of 14 of the 26 activities. The following engineering activities were among the most used: designing rubber-band powered cars (Design Squad), designing bridges (EiE), designing your own roller coaster ride, designing alarm circuits (EiE), and designing houses for the three little pigs. These lessons and activities target the following science concepts: different forms of energy, conservation of energy, forces, and electricity.

An analysis of covariance (ANCOVA) was conducted to see if the number of lessons or activities conducted by teachers had an effect on their posttest scores (taken as an indicator of content knowledge). When the teachers' pretest scores were added as a covariate, this model explained 60 percent of the variance in teachers' posttest scores. In other words, *since all teachers were exposed to the same lessons in the workshops, implementing these lessons in their classroom played a major role in the increased posttest results*. In addition, for 18 of the 26 activities, including four of the five engineering activities, 100 percent of the teachers who had used them reported that they would use them again next year.

Finally, teachers were asked if they would have liked to use more of the project lessons and if so, what stopped them from doing so. Thirty-one out of the 44 teachers mentioned time constraints as one of the reasons for not being able to use more project lessons. For many of the teachers, *test prep took priority over conducting hands-on activities*. In grades where teachers could not connect/link activities to the curriculum standards, the activities became additional content to be covered in a *limited time*. Some teachers solved this problem by using activities they learned in previous institutes or by creating their own activities based on the knowledge/experience they had gained over the past three years. *Having students who were not well prepared* also made it difficult for some teachers to integrate the project activities. Some teachers also noted that it took time to prepare for project activities as well as to conduct them during short class periods. In addition to the time constraints, five teachers mentioned *lack of materials* as a deterrent in using more activities in the classroom. Another reason was *different curriculum or pedagogical focus of the school/administration*.

Students

The biggest learning issue is that the students have limited background knowledge to science. The PISA activities allow students to gain knowledge as they learn, regardless of what stage of learning they are in. *—5th grade inclusion teacher*

Instrument

Pre and posttests were developed to assess students' content knowledge in both groups. There were 19 questions – 14 science and science-related mathematics and five engineering. A total of 1,565 students (796 PISA students and 769 comparison students) took the pretest at the beginning of the school year (September 2009). All 39 lead PISA teachers and 36 of the 38 comparison teachers returned both tests; therefore, the total number of student tests that could be matched (pre with post) was 1,179 (638 PISA students and 541 comparison students). The science questions were taken from the 4th or 5th grade level questions published on line by the TIMSS, MOSART, and A Private Universe Project. Engineering questions were selected from the EiE evaluation questions developed by the Museum of Science, Boston. Tests were administered to the treatment and comparison groups in September 2008 and May 2009.

Results

Both PISA and the comparison students had a minimum pretest score of 0 out of 19 and a maximum score of 16. The PISA students' mean pretest score ($M=6.68$, $SD=2.535$) was slightly lower than the comparison students' mean pretest score ($M=7.16$, $SD=2.619$). When looking at each group separately, the treatment group had a significant increase in its posttest scores – from $M=6.68$ to $M=9.77$ [$t(637) = -23.543$, $p<.01$]. This was a 46 percent increase. Although the comparison group also had a significant increase in its posttest scores, from $M=7.16$ to $M=8.39$ [$t(540) = -10.346$, $p<.01$], the increase was only 17 percent. Since the difference between the two groups on the pretest was statistically significant [$t(1177) = -3.188$, $p<.01$], an analysis of covariance (ANCOVA) was used in the analysis of the posttest scores in order to control for the differences in the pretest scores. This showed that the difference in posttest scores between the two groups was significant [$F(1,1176) = 100.079$, $p<.01$] when the pretest scores were held constant. *In other words, treatment students improved significantly more than comparison students did when their slightly lower pretest scores were taken into account. When the students' pretest scores were held constant, the treatment students had higher posttest scores (M=9.869) than the comparison students (M=8.282).*

When the teachers' posttest scores were added as another variable, they were a significant predictor of the students' posttest scores [$F(1,1162) = 56.412$, $p<.01$]. Furthermore, the interaction component (of group and teacher posttest score) was significant. *In other words, if two teachers (one treatment, one comparison) had equal posttest scores, the treatment teachers' students were more likely to do well than the comparison teachers' students.* The project activities therefore contributed to the students' posttest scores. An analysis of covariance (ANCOVA) was performed to examine if the number of activities conducted in the classroom would explain the variance in the students' posttest scores. Students' pretest scores were used as a covariate to adjust for the variability in the pretest. *The number of activities students were exposed to in the classroom was a statistically significant predictor of their posttest scores.*

When the teachers' posttest scores (signifying teacher content knowledge) were added as another independent variable, the model improved further (R Squared = .477). The number of activities conducted in the classroom, the teacher posttest score (signifying teacher content knowledge), and the students' pretest scores explained 47 percent of the variance in the students' posttest scores; 30 percent of this can be attributed to the number of activities conducted. In addition, the interaction effect between total number of activities and teacher posttest scores was one of the significant predictors. This suggests that 1) *the more activities a teacher performed, the higher the students' posttest scores* and 2) *when activities were conducted by teachers with higher posttest scores, students' posttest scores were higher.*

Results: Integrating the EDP into the science curriculum

Five engineering design activities were introduced during Year 3. Over half of the students were exposed to three or more of the five activities. The analysis of covariance (ANCOVA) was performed to examine if the number of engineering activities conducted in the classroom explained the variance in the students' posttest scores on science questions. Students' science pretest scores were used as a covariate to adjust for the variability in the pretest. The model explained 24 percent of the variability in students' posttest scores on the science questions. *The number of engineering activities to which the students were exposed in the classroom was a significant predictor of their science posttest scores.*

Key insights

The purpose of the PISA study was to examine the PD program in terms of its contributions to teachers' content knowledge, teachers' classroom implementation of project activities, and students' content knowledge. The program was designed, in part, in response to the challenges presented by the National Academy of Engineering (2009) to help teachers implement science and engineering lessons in elementary classrooms. We chose a PD model described in the literature by Kennedy (1998). This path or model targets an improvement in students' content knowledge and 21st century skills through changes in teachers' knowledge and teaching practices. Based on our analysis of pre and posttests given to teachers, the treatment teachers' posttest scores improved significantly compared to the comparison group, even when the treatment teachers' higher pretest scores were taken into account. Teachers in the treatment group improved their content knowledge in specific physical science and engineering concepts after one year of continuous PD. These findings were similar to the reviews of Ingvarson, Meiers, and Beavis (2005), which showed improvements in teachers' knowledge as a result of intensive professional development programs. Our analysis also suggested that PISA teachers implemented almost half of the lessons in their own classrooms, specifically engineering, which played a major role in their increased posttest results. Teachers mentioned time constraints due to test preparations, students' varied content knowledge background, and different curriculum and pedagogical focus in schools as factors that deterred them from implementing more PISA lessons.

Students of both treatment and comparison teachers showed significant increases in their mean posttest scores, although treatment teacher students improved significantly more than comparison teacher students did when their slightly lower pretest scores were taken into account. Further analysis of teacher and student test scores revealed that teacher posttest scores were a significant predictor of their students' posttest scores. This suggested the test itself might be better tied to the content being taught by teachers. These findings were reflective of research reviews conducted by Blank & de las Alas (2009), which reported correlation between PD for teachers and student achievement. In addition, our study has shown the implication of promoting the EDP in teacher PD. The engineering design lessons engaged teachers as well as students in learning the required science concepts. The number of engineering activities to which the students were exposed in the classroom was a significant predictor of their science posttest scores.

The key components of the PISA PD program (content workshops and classroom visits) and focus (science and engineering) led us to its expansion and the development of the PISA^2 program. In PISA^2, science and engineering content and practices will be delivered in five graduate science courses, while the pedagogical content knowledge will be enhanced in the additional workshops and classroom support visits. These components aim to increase the success of enhancing teachers' content knowledge, beliefs, and practices towards implementing science and engineering in Grade 3-8 classrooms; and as the end result, improving the content knowledge and attitudes of their students.

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