AC 2007-2397: ASSESSMENT RESULTS FROM A THREE-YEAR PROJECT TO TEACH ENGINEERING IN GRADES K-6

John Orr, Worcester Polytechnic Institute

JOHN A. ORR is Dean of Undergraduate Studies and Professor of Electrical and Computer Engineering at WPI. He is active professionally in the area of engineering education as well as in the technical field of geolocation systems. He was recently named a Fellow of the Institute of Electrical and Electronics Engineers for his work in engineering education. Telephone 508-831-5723; email orr@wpi.edu.

Paula Quinn, Independent Consultant

PAULA QUINN is a Research Manager at the Donahue Institute of the University of Massachusetts, focusing on assessment of pre-K through post-secondary education programs and of professional development programs for educators. She has worked on projects relating primarily to the areas of literacy, science, technology, engineering, and math. Prior to joining the Donahue Institute, she worked as an independent assessment and evaluation consultant. Ms. Quinn received an M.A. in Developmental Psychology from Clark University and a B.A. in Psychology from Case Western Reserve University.

Jill Rulfs, Worcester Polytechnic Institute

JILL RULFS is Associate Professor of Biology & Biotechnology at WPI. In addition to being a former public school teacher herself, she has remained active in university/public school partnerships. She has served as a consultant for the Massachusetts Biotechnology Research Institute on K-12 education and edited Biotechnology: The Technology of Life, a sourcebook for K-12 classroom teachers. Phone 508-831-5786; email jrulfs@wpi.edu.

Assessment Results from a Three-Year Project to Teach Engineering in Grades K-6

Abstract

Assessment results from a three-year project to teach engineering in grades K through six conducted as part of the NSF Graduate Teaching Fellows in K-12 Education (GK-12) program are presented. This project involved 18 graduate fellows, 33 public school teachers, and approximately 1000 students in grades K-6 in an urban school system. An unusual aspect of the project is that it brought the teaching of engineering to the earliest grades. Project goals included specific positive impacts on the fellows and teachers as well as on the elementary school students. Assessment results demonstrate substantial positive outcomes for the teachers and fellows but results are inconclusive for the students, perhaps due to the assessment techniques employed.

Introduction and Project Overview

During the three-year period from fall, 2003 to spring, 2006, WPI participated in the NSF Graduate Teaching Fellows in K-12 Education (GK-12) program. WPI's project, titled "K-6 Gets a Piece of the PIEE (Partnerships Implementing Engineering Education)," brought graduate teaching fellows and undergraduate students into the Worcester Public School System, involving three schools with quite different socioeconomic environments.

Massachusetts is one of the few states to have mandated the teaching of engineering and technology topics from kindergarten through grade twelve and the PIEE project addressed grades K through 6. Previous papers[1,2] have described the project, presented "lessons learned," and explained the means by which engineering can be taught at the kindergarten and grade one levels. A companion paper[3] provides an overall summary of the PIEE project. This paper presents assessment results and conclusions from the three-year project that involved a total of 8 WPI faculty, 18 WPI graduate students, 32 WPI undergraduate students, three schools, 33 teachers, and approximately 1000 Worcester Public School students.

The PIEE project was rather complex organizationally, with involvement of several different groups of people:

- Elementary school teachers, grades K-6,
- Students in grades K-6,
- WPI graduate student fellows,
- WPI undergraduate students,
- WPI faculty as project investigators and mentors/advisors to the fellows and undergraduate students.

The fellows represented the primary means by which the teaching of engineering and technology was to be enhanced. The most important role of the fellows was to help the classroom teachers develop their skills in the teaching of engineering and technology, as opposed to actually doing that teaching themselves. In fact, the need to help classroom teachers overcome their uncertainty

and apprehension regarding their ability to teach engineering concepts was a major aspect of the overall program. The WPI undergraduates played an important supporting role in developing lesson plans and assisting in the classrooms, but were not key to the fundamental project goals.

The PIEE project was designed to positively influence each of the following:

- Teacher preparation for teaching engineering,
- Student interest in technology and engineering,
- Fellow interest and engagement with engineering education,
- Fellow communication abilities,
- Fellow teaching skills.

Assessment of the level of accomplishment of these goals was an important focus of the PIEE project, and is the subject of this paper.

Assessment Methods

Evaluation of the program was initially designed to utilize a quasi-experimental process regarding teacher- and student-related goals and to utilize a within-subjects design regarding fellow-related goals. A quasi-experimental design was used for year one for teachers and students, but it was not possible to continue using that design after year one because in years two and three the project was expanded within schools that had participated beginning in year one and adequate numbers of comparison teachers and classrooms were no longer available. For years two and three, within-subjects designs were used to evaluate impact on fellows, teachers, and students.

Self-report paper-and-pencil surveys administered at the beginning and end of each program year were the primary data sources for of all groups involved in this evaluation. Program-designed surveys for each group consisted primarily of Likert scale items, with surveys for students relying on smiley-, neutral-, and frowny-faced icons instead of text for response choices. At the end of year one, a focus group was conducted with teachers who had participated in year one, and information from that focus group was used formatively for program development for year two. The evaluator and PI collaboratively designed a focus group protocol that focused on issues related to immediate program improvement.

Pre-program surveys were administered to fellows and teachers at the beginning of their respective orientations for each program year; post-program surveys were administered either in person or via ground mail, depending on participant availability. Teachers administered pre- and post-program surveys to their own classroom students at both the beginning and end of each academic year. For each year, teachers were asked to administer pre-program surveys to their students prior to the first science class of the year and they were asked to administer post-program surveys as late in the academic year as was possible. Comparison group teacher surveys in year one were administered both pre- and post-program surveys via ground mail, and student surveys were delivered to comparison teachers via ground mail, and those teachers were given the same instructions for administration to their students that participating teachers were given. Comparison group teachers were offered an incentive of a gift card to a local bookstore for participating in the data collection efforts.

Because all surveys utilized ordinal scales, Wilcoxon matched pairs tests were used to determine the statistical significance of pre-to-post program changes within any particular group. For year one, because the participant groups and comparison groups did not have equal sample sizes, Mann-Whitney *U* tests were used to determine the statistical significance of differences between groups. For all analyses, findings with $p < .05$ were considered statistically significant. Only participants completing both pre- and post-program surveys were included in analyses.

Review of Findings

Findings indicate that the PIEE program positively influenced fellow and teacher participants. Findings regarding impact on students of PIEE teachers are somewhat ambiguous, and it is likely that the method of data collection used for students was not optimal for the student population in this project. Findings with respect to each of the primary participant groups are presented below. Quantitative results are reported in Appendix A which contains both raw response frequencies and statistical analysis to indicate significance.

Fellows

For the 2003-2004 and 2004-2005 program years, seven fellows completed both pre- and post-program surveys, and for the 2005-2006 program year, six fellows completed both pre- and post-program surveys.

For the 2003-2004 program year, statistically significant findings show that between the beginning of the program and the end of the program, fellows believe they improved their teaching skills. Statistical details regarding these findings may be found in Appendix A, Tables A1 and A2. Specifically, results showed improvements in fellows' perceptions of their abilities to help students reach specific learning goals as outlined in the Massachusetts Department of Education curriculum frameworks for technology and engineering. For each of the following learning standards, fellows' pre-program survey responses indicated that they were able to help students either "neither poorly nor well" or between "neither poorly nor well" and "well" while their post-program responses indicated that they were between "well" and "very well" able to help students:

- Understand how to identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem
- Learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task
- Identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design
- Understand the various methods of representing solutions to design problems
- Describe and explain the purpose of a given prototype.

Fellows' beliefs in the value of their work in terms of the students remained strong throughout the 2003-2004 year, with fellows at both the beginning and end of the program believing between "much" and "very much" that they had "something valuable to offer." Fellows' beliefs in the value of their work in terms of the teachers showed a statistically significant decline

between the beginning and end of the program, though. Initially, fellows believed "very much" that they had something valuable to offer while at the end of the program they believed only "much" that they did.

For the 2004-2005 program year, statistically significant findings show that between the beginning of the program and the end of the program, fellows believed they improved their teaching and communication skills. Statistical details regarding these findings may be found in Appendix A, Tables A3 and A4. Specifically, results showed improvements in fellows' perceptions of their abilities to do each of the following activities:

- Develop a lesson plan
- Identify appropriate learning goals regarding engineering for students in a grade between K and 6
- Design learning activities to teach engineering to students in a grade between K and 6
- Given a particular concept in engineering, explain to teachers how to help their students, who are in a grade between K and 6, understand it.

For each of these activities, fellows initially indicated that they were able to do them "well," while at the end of the year, they indicated that they were able to do them "very well."

Fellows' beliefs in the value of their work in terms of the teachers they worked with showed a statistically significant increase between the beginning and end of the program. Initially, fellows believed "much" that they had something valuable to offer, while at the end of the program they believed "very much" that they did.

Fellows' beliefs that their position in the PIEE program would enhance their ability to pursue graduate work showed a statistically significant decline from the beginning of the year to the end of the year. Initially, they believed their position would "much" enhance their ability to pursue graduate work, and later they believed that it would only enhance it "moderately."

For the 2005-2006 program year, statistically significant findings show that between the beginning of the program and the end of the program, fellows believed they improved their teaching and communication skills. Statistical details regarding these findings may be found in Appendix A, Tables A5 and A6. Specifically, results showed improvements in fellows' perceptions of their abilities to do each of the following activities:

- Help others develop a level of comfort with a topic that they may initially perceive as intimidating
- Design learning activities to teach engineering to students in a grade between K and 6
- Given a particular concept in engineering, explain to teachers how to help their students, who are in a grade between K and 6, understand it
- Teach students in a grade between K and 6 about issues related to engineering.

Over the course of the three years of the project, fellows' improvements occurred in areas that were progressively more general and more broadly applicable. It is likely that because fellows participating in each successive year were building on the technical and logistical foundations laid by their predecessors, they were able to devote more of their energy and efforts to working on the especially interpersonally challenging areas of communication and teaching.

Teachers

For the 2003-2004 program year, six PIEE teachers and four non-PIEE teachers completed both pre- and post-program surveys; 15 PIEE teachers completed both for the 2004-2005 program year; and 11 PIEE teachers completed both for the 2005-2006 program year.

Between-groups Differences

For the 2003-2004 program year, PIEE teachers entering the PIEE program ascribed more importance to teaching children about engineering than did non-PIEE teachers. In addition, at the beginning of the year, when compared to non-PIEE teachers, PIEE teachers indicated higher levels of ability at helping students do each of the following:

- Understand the steps of the engineering design process
- Understand the various methods of representing solutions to design problems
- Describe and explain the purpose of a given prototype.

Statistical details regarding these 2003-2004 pre-program survey findings may be found in Appendix A, Table A7.

Analyses of these same post-survey items reveal the same pattern of responses, but because differences between the groups existed on the pre-survey, the post-survey differences should be considered with caution.

On the post-survey, when compared to non-PIEE teachers, PIEE teachers gave statistically significantly higher ratings to their abilities to do each of the following:

- Design learning activities to teach students about engineering
- Teach students about issues related to engineering
- Help students do each of the following:
    - Identify an engineering problem that reflects a need for shelter, storage, or convenience
    - Understand how to identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem
    - Learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task
    - Identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design
    - Understand how design features (e.g., size, shape, weight, function, cost limitations) affect the construction of a given prototype.

In addition, when compared to the non-PIEE teachers, PIEE teachers expressed statistically significantly higher post-survey interest in developing each of the following:

- An understanding of basic engineering principles
- Relationships with other primary education teachers to help them to better understand engineering education.

Statistical details regarding these 2003-2004 post-program survey findings may be found in Appendix A, Table A8.

Within-group Change

For the 2003-2004 program year, non-PIEE teachers showed no statistically significant changes between the pre- and post-surveys.

For each program year, between the pre-and post-surveys, PIEE teachers showed statistically significant changes in many areas. In all cases, findings indicated that the program was having positive effects that were aligned with program goals. PIEE teacher survey responses revealed statistically significant improvement in their perceptions of their abilities. Statistical details regarding these 2003-2004 findings may be found in Appendix A, Tables A9 and A10. Specifically, in 2003-2004, improvements were seen in perceptions of each the following abilities:

- Incorporating goals of the Massachusetts Science and Technology/Engineering Framework into the curriculum
- Understanding basic engineering concepts
- Teaching students about issues related to engineering
- Helping students do the following:
    - Learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task
    - Understand different tools, their purposes, and their safe and proper usage
    - Identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design
    - Understand the steps of the engineering design process
    - Understand the various methods of representing solutions to design problems
    - Describe and explain the purpose of a given prototype
    - Understand how design features (e.g., size, shape, weight, function, cost limitations) affect the construction of a given prototype
    - Understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback).

For the 2004-2005 program year, PIEE teacher survey responses revealed statistically significant improvement in perceptions of ability in each of the following:

- Incorporating the goals of the Massachusetts Science and Technology/ Engineering Framework into the curriculums they were using
- Understanding basic engineering concepts
- Teaching students in a grade between K and 6 about issues related to engineering
- Enhancing content knowledge and understanding of principles of engineering for teachers who teach in a grade between K and 6

- Designing learning activities to teach engineering to students in a grade between K and 6
- Given a particular concept in engineering, explaining to another teacher how to help their students, who are in a grade between K and 6, understand it
- Helping students do the following:
    - Understand the process involved in constructing a prototype
    - Understand the difference between simple and complex machines
    - Make comparisons between natural systems and mechanical systems that serve similar purposes
    - Understand different tools, their purposes, and their safe and proper usage
    - Understand the steps of the engineering design process
    - Understand the various methods of representing solutions to design problems
    - Describe and explain the purpose of a given prototype
    - Understand how design features affect the construction of a given prototype
    - Understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback).

In addition, for the 2004-2005 program year, PIEE teacher survey responses also revealed statistically significant increases in each of the following:

- Interest in promoting the expansion of engineering education in the primary curriculum
- Belief that participating in the PIEE program will enhance their ability to carry out typical teaching duties
- Belief that they have something valuable to offer the other teachers with whom they are working through the PIEE program.

Statistical details regarding significant 2004-2005 teacher survey findings may be found in Appendix A, Tables A11 and A 12.

For the 2005-2006 program year, PIEE teacher survey responses revealed statistically significant increases in their perceptions of their abilities in each of the following:

- Understanding of basic engineering concepts
- Ability to teach students in a grade between K and 6 about issues related to engineering
- Ability to enhance content knowledge and understanding of principles of engineering for other teachers who teach in a grade between K and 6
- Helping a student understand how tools and simple machines are used for specific purposes.

Statistical details regarding significant 2004-2005 teacher survey findings may be found in Appendix A, Tables A13 and A 14.

Teacher Comments

Appendix B contains verbatim comments from teachers in response to a question asking for the extent to which the PIEE program met the teacher's expectations. The following represent the recurring comment themes:

- Teachers' understanding of engineering as an academic discipline as well as profession was increased.
- Teachers' confidence in their abilities to teach engineering concepts was increased.
- The contributions of the graduate student fellows were substantial and varied, ranging from the lesson plans that they produced to the positive role models that they represented to the students.

Students

Between-groups Differences

For the 2003-2004 program year, 93 students of six PIEE teachers and 55 students of four non-PIEE teachers completed both pre- and post-program surveys.

At the beginning of the year, students of PIEE teachers were statistically significantly more interested than students of non-PIEE teachers in both "rockets and traveling into space" and "energy (heat, light, sun)," but by the end of the year, there were no statistically significant differences in interest between the groups. At the beginning of the year, there were no statistically significant differences in interest between the groups in either "tools and building things" or "engineering (making things that solve problems, like toasters or bridges)," but at the end of the year, students of PIEE teachers were statistically significantly more interested in those areas than were students of non-PIEE teachers. Tables A15 and A16 in Appendix A provide statistical details regarding these significant comparative differences.

Within-group Change

For the 2003-2004 program year, 93 students of six PIEE teachers completed both pre and post-program surveys; for the 2004-2005 program year, 190 students of 13 PIEE teachers completed both pre- and post-program surveys; and for the 2005-2006 program year, 226 students of 14 PIEE teachers completed both pre- and post-program surveys.

While findings regarding program impact on fellows and teachers reveal certain thematic consistencies across all three years of the program, findings for program impact on students do not. For both the 2003-2004 program year and the 2004-2005 program year, students of PIEE teachers showed statistically significant declines in interest in "doing a science project," but no change was seen in this area during the 2005-2006 program year. In the 2004-2005 program year, students of PIEE teachers showed a statistically significant decline in interest in "electricity," but they showed a statistically significant increase in interest in "engineering (making things that solve problems, like toasters or bridges)." No statistically significant changes in any area occurred for the 2005-2006 program year. Tables A17 and A18 provide statistical details regarding significant student survey findings across all years.

Feedback from PIEE teachers regarding survey administration to their students indicated that student survey responses at times seemed very strongly influenced by immediate classroom

conditions and that survey administration at the end of the academic year was especially difficult because many students were anticipating summer vacation and were not focused on classroom work. In addition, despite a survey design that minimized the use of text to the fullest extent possible, some teachers indicated that English Language Learners and Special Education students still had difficulty completing the surveys.

An observational measure of student interest may have yielded more reliable data than the PIEE project student self-report interest survey did, but time and cost constraints prohibited consideration of the use of such an approach.

Conclusions

A brief summary of conclusions with respect to each of the project goals is presented here.

Teacher preparation for teaching engineering

The statistical results and teacher comments demonstrate that this goal was achieved. Prior to the program teachers exhibited a rather high level of uncertainty and apprehension about the topic of engineering and the appropriate means to teach it. The PIEE program successfully addressed these important aspects.

Student interest in technology and engineering

The assessment results are unable to demonstrate achievement of this goal. It is recommended that future studies implement two approaches that were not used here: (1) an observational approach rather than the written survey approach, and (2) longer-term longitudinal studies to investigate knowledge and attitudes one or more years after the introduction to engineering.

Fellow interest and engagement with engineering education

The performance of the fellows demonstrated a high level of engagement with engineering education at the K-6 levels. Pre and post surveys demonstrated substantial growth in teaching skills of the fellows.

Fellow communication abilities

Survey results document improvements in communications skills as related to the K-6 students, and to the teachers. No doubt these skills will be useful to the fellows outside of this particular environment

Fellow teaching skills

Pre and post surveys demonstrate improvements in the various aspects involved in teaching, from developing lesson plans to developing age-appropriate learning activities.

An aspect of the project that was not directly assessed was the commitment of time and effort on everyone's part that was required. For the fellows, this represented the one negative aspect of the project in that this time commitment impacted somewhat negatively on their own graduate student studies.

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Appendix A

Table A1. Details of statistically significant Wilcoxon matched pairs tests for 2003-2004 fellow survey items

Item Focus	*N*	*T*	*Z*	*p*
Extent to which currently able to help a 4th or 5th grade student understand how to identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem (Item 40)	6	0.00	2.02	.043
Extent to which currently able to help a 6th grade student learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task (Item 42)	6	0.00	2.02	.043
Extent to which currently able to help a 6th grade student identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design (Item 44)	6	0.00	2.02	.043
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems (Item 46)	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype (Item 47)	6	0.00	2.02	.043
How much believe has something valuable to offer the teachers in the project (Item 69)	6	0.00	2.02	.043

Table A2. Response frequencies for statistically significant 2003-2004 fellow survey items

		Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to help a 4th or 5th grade student understand how to identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem (Item 40)	6	1	0	0	0	0	0	4	0	0	2	1	4
Extent to which currently able to help a 6th grade student learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task (Item 42)	6	0	0	0	0	0	0	4	0	1	2	1	4
Extent to which currently able to help a 6th grade student identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design (Item 44)	6	0	0	0	0	0	0	4	1	2	1	0	4
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems (Item 46)	6	0	0	0	0	0	0	5	0	1	2	0	4
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype (Item 47)	6	1	0	0	0	0	0	4	0	0	2	1	4
		Not at All		Only a Little		Moderately		Much		Very Much			
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*		
How much believe has something valuable to offer the teachers in the project (Item 69)	6	0	0	0	0	0	2	2	4	4	0		

Table A3. Details of statistically significant Wilcoxon matched pairs tests for 2004-2005 fellow survey items

Item Focus	***N***	***T***	***Z***	***p***
Extent to which currently able to develop a lesson plan (Item 28)	7	0.00	2.37	.018
Extent to which currently able to identify appropriate learning goals regarding engineering for students in a grade between K and 6 (Item 30)	7	0.00	2.20	.028
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6 (Item 31)	7	0.00	2.20	.028
Extent to which currently able to explain to teachers how to help students in grades K – 6 understand a particular concept in engineering (Item 34)	6	0.00	2.02	.043
How much believe position as a Fellow in the program enhances ability to pursue graduate work (Item 68)	7	0.00	2.20	.028
How much believe has something valuable to offer the teachers in the project (Item 69)	7	0.00	2.02	.043

Table A4. Response frequencies for statistically significant 2004-2005 fellow survey items

		Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to develop a lesson plan (Item 28)	7	0	0	0	0	0	0	3	0	4	1	0	6
Extent to which currently able to identify appropriate learning goals regarding engineering for students in a grade between K and 6 (Item 30)	7	0	0	0	0	0	0	2	0	4	1	1	6
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6 (Item 31)	7	0	0	0	0	0	0	3	0	3	1	1	6
Extent to which currently able to explain to teachers how to help students in grades K – 6 understand a particular concept in engineering (Item 34)	6	0	0	0	0	0	0	2	0	4	2	0	4
		Not at All		Only a Little		Moderately		Much		Very Much			
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*		
How much believe position as a Fellow in the program enhances ability to pursue graduate work (Item 68)	7	0	0	0	2	2	4	3	1	2	0		
How much believe has something valuable to offer the teachers in the project (Item 69)	7	0	0	0	0	1	0	4	0	2	7		

Table A5. Details of statistically significant Wilcoxon matched pairs tests for 2005-2006 fellow survey items

Item Focus	***N***	***T***	***Z***	***p***
Extent to which currently able to help others develop a level of comfort with a topic that they may initially perceive as intimidating (Item 22)	6	0.00	2.02	.043
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6 (Item 31)	6	0.00	2.20	.023
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering (Item 32)	6	0.00	2.20	.023
Extent to which currently able to explain to teachers how to help students in grades K – 6 understand a particular concept in engineering (Item 34)	6	0.00	2.02	.043

Table A6. Response frequencies for statistically significant 2005-2006 fellow survey items

Item Focus	N	Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		n	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to help others develop a level of comfort with a topic that they may initially perceive as intimidating (Item 22)	6	0	0	0	0	0	0	0	0	6	1	0	5
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6 (Item 31)	6	0	0	0	0	0	0	2	0	4	0	0	6
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering (Item 32)	6	0	0	0	0	0	0	2	0	4	1	0	5
Extent to which currently able to explain to teachers how to help students in grades K – 6 understand a particular concept in engineering (Item 34)	6	0	0	0	0	0	0	2	0	4	1	0	5

Table A7. Details of statistically significant Mann-Whitney *U* tests comparing pre-program survey responses for program teachers (PIEE) and non-program (Not PIEE) teachers for 2003-2004

Item Focus	Rank Sum		Valid *N*		*U*	*Z**	*p*
	PIEE	Not PIEE	PIEE	Not PIEE			
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	38.00	7.00	6	3	1.00	2.15	.032
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	36.00	9.00	6	3	3.00	2.12	.034
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	36.50	8.50	6	3	2.50	1.99	.046
Extent believed it was important to teach children about engineering	42.00	13.00	6	4	3.00	2.12	.034

* Adjusted for ties

Table A8. Details of statistically significant Mann-Whitney *U* tests comparing post-program survey responses for program teachers (PIEE) and non-program (Not PIEE) teachers for 2003-2004

Item Focus	Rank Sum		Valid *N*		*U*	*Z**	*p*
	PIEE	Not PIEE	PIEE	Not PIEE			
Extent to which currently able to design learning activities to teach 4th, 5th, or 6th grade students about engineering	45.00	10.00	6	4	0.00	2.74	.006
Extent to which currently able to teach 4th, 5th, or 6th grade students about issues related to engineering	42.50	12.50	6	4	2.50	2.29	.022
Extent to which currently able to help a 4th or 5th grade student identify an engineering problem that reflects a need for shelter, storage, or convenience	43.50	11.50	6	4	1.50	2.41	.016
Extent to which currently able to help a 4th or 5th grade student understand how to identify relevant design features for building a prototype of a solution to a given problem	42.50	12.50	6	4	2.50	2.09	.037
Extent to which currently able to help a 6th grade student learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task	43.50	11.50	6	4	1.50	2.37	.018
Extent to which currently able to help a 6th grade student identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design	44.00	11.00	6	4	1.00	2.54	.011
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	45.00	10.00	6	4	0.00	2.68	.007
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	45.00	10.00	6	4	0.00	2.66	.008
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	44.00	11.00	6	4	1.00	2.45	.014
Extent to which currently able to help a 6th grade student understand how design features affect the construction of a given prototype	43.00	12.00	6	4	2.00	2.21	.027
Extent interested in developing an understanding of basic engineering principles	41.50	13.50	6	4	3.50	2.07	.038
Extent interested in developing relationships with other primary education teachers to help them to better understand engineering education	41.50	13.50	6	4	3.50	2.05	.040

* Adjusted for ties

Table A9. Details of statistically significant Wilcoxon matched pairs tests for 2003-2004 program teacher survey items

Item Focus	***N***	***T***	***Z***	***p***
Extent to which currently able to incorporate the goals of the Massachusetts Science and Technology/Engineering Framework into the curriculum currently using	6	0.00	2.02	.043
Extent to which currently able to understand basic engineering concepts	6	0.00	2.02	.043
Extent to which currently able to teach 4th, 5th, or 6th grade students about issues related to engineering	5	0.00	2.02	.043
Extent to which currently able to help a 6th grade student learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task	6	0.00	2.02	.043
Extent to which currently able to help a 6th grade student understand different tools, their purposes, and their safe and proper usage	6	0.00	2.02	.043
Extent to which currently able to help a 6th grade student identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student understand how design features affect the construction of a given prototype	6	0.00	2.20	.028
Extent to which currently able to help a 6th grade student understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback	6	0.00	2.02	.043

Table A10. Response frequencies for statistically significant 2003-2004 program teacher survey items

Item Focus	N	Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		n	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to incorporate the goals of the Massachusetts Science and Technology/Engineering Framework into the curriculum currently using	6	0	0	0	0	2	0	3	0	1	3	0	3
Extent to which currently able to understand basic engineering concepts	6	0	0	1	0	1	0	2	1	2	4	0	1
Extent to which currently able to teach 4th, 5th, or 6th grade students about issues related to engineering	5	0	0	1	0	0	0	3	0	1	5	0	1
Extent to which currently able to help a 6th grade student learn how to identify appropriate materials based on specific properties and characteristics, given a particular design task	6	0	0	0	0	1	0	2	0	3	3	0	3
Extent to which currently able to help a 6th grade student understand different tools, their purposes, and their safe and proper usage	6	0	0	0	0	0	0	2	0	4	2	0	4
Extent to which currently able to help a 6th grade student identify and explain the safe and proper usage of tools needed to construct a prototype, given a particular engineering design	6	0	0	0	0	1	0	2	0	3	1	0	5
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	6	0	0	0	0	1	0	3	0	2	2	0	4
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	6	0	0	0	0	0	0	6	0	0	2	0	4
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	6	0	0	0	0	0	0	5	0	1	2	0	4
Extent to which currently able to help a 6th grade student understand how design features affect the construction of a given prototype	6	0	0	0	0	1	0	3	1	2	1	0	4
Extent to which currently able to help a 6th grade student understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback	6	3	0	0	1	1	0	2	2	0	1	0	2

Table A11. Details of statistically significant Wilcoxon matched pairs tests for 2004-2005 program teacher survey items

Item Focus	***N***	***T***	***Z***	***p***
Extent to which currently able to incorporate the goals of the Massachusetts Science and Technology/Engineering Framework into the curriculum currently using	14	3.00	2.50	.013
Extent to which currently able to understand basic engineering concepts	14	0.00	2.93	.003
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6	14	0.00	2.80	.005
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering	13	4.50	2.53	.011
Extent to which currently able to enhance content knowledge and understanding of principles of engineering for teachers who teach in a grade between K and 6	14	0.00	2.37	.018
Extent to which currently able to explain to another teacher how to help students in grades between K and 6 understand a particular concept in engineering	13	0.00	2.80	.005
Extent to which currently able to help a grade 3, 4, or 5 student understand the process involved in constructing a prototype	14	0.00	2.52	.012
Extent to which currently able to help a grade 3, 4, or 5 student understand the difference between simple and complex machines	14	0.00	2.37	.018
Extent to which currently able to help a grade 3, 4, or 5 student make comparisons between natural systems and mechanical systems that serve similar purposes	14	0.00	2.52	.012
Extent to which currently able to help a 6th grade student understand different tools, their purposes, and their safe and proper usage	13	3.50	2.03	.042
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	13	2.00	2.60	.009
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	13	7.00	2.09	.037
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	13	0.00	2.37	.018
Extent to which currently able to help a 6th grade student understand how design features affect the construction of a given prototype	13	2.00	2.24	.025
Extent to which currently able to help a 6th grade student understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback	13	4.00	2.40	.017
Extent interested in promoting the expansion of engineering education in the primary curriculum	11	0.00	2.02	.043
How much believe position as teacher in this program enhances ability to carry out typical teaching duties	12	4.00	2.19	.028
How much believe has something valuable to offer other teachers in this program	12	3.50	2.03	.042

Table A12. Response frequencies for statistically significant 2004-2005 program teacher survey items

Item Focus	N	Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		n	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to incorporate the goals of the Massachusetts Science and Technology/Engineering Framework into the curriculum currently using	14	0	0	0	0	0	0	7	0	5	6	2	8
Extent to which currently able to understand basic engineering concepts	14	0	0	0	0	6	0	4	3	4	8	0	3
Extent to which currently able to design learning activities to teach engineering to students in a grade between K and 6	14	0	0	0	0	2	0	9	2	2	9	1	3
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering	13	0	0	0	0	5	0	4	4	4	6	0	3
Extent to which currently able to enhance content knowledge and understanding of principles of engineering for teachers who teach in a grade between K and 6	14	0	0	0	0	3	0	8	6	3	6	0	2
Extent to which currently able to explain to another teacher how to help students in grades between K and 6 understand a particular concept in engineering	13	0	0	0	0	2	0	9	2	2	8	0	3
Extent to which currently able to help a grade 3, 4, or 5 student understand the process involved in constructing a prototype	14	0	0	0	0	1	0	8	3	4	8	1	3
Extent to which currently able to help a grade 3, 4, or 5 student understand the difference between simple and complex machines	14	0	0	0	0	1	0	5	1	7	9	1	4
Extent to which currently able to help a grade 3, 4, or 5 student make comparisons between natural systems and mechanical systems that serve similar purposes	14	0	0	0	0	2	0	6	1	5	10	1	3
Extent to which currently able to help a 6th grade student understand different tools, their purposes, and their safe and proper usage	13	0	0	0	0	2	0	3	0	5	9	3	4
Extent to which currently able to help a 6th grade student understand the steps of the engineering design process	13	3	0	0	0	3	0	3	1	2	9	2	3
Extent to which currently able to help a 6th grade student understand the various methods of representing solutions to design problems	13	1	0	0	0	3	0	5	4	2	6	2	3
Extent to which currently able to help a 6th grade student describe and explain the purpose of a given prototype	13	3	0	0	0	3	0	2	3	3	7	2	3

Extent to which currently able to help a 6th grade student understand how design features affect the construction of a given prototype	13	3	0	0	0	1	0	5	5	2	5	2	3
Extent to which currently able to help a 6th grade student understand the five elements of a universal systems model (goal, inputs, processes, outputs, and feedback	13	4	0	2	0	2	2	4	7	1	3	0	1

		Not at All		Just a Little		Somewhat		Interested		V.Interested			
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*		
Extent interested in promoting the expansion of engineering education in the primary curriculum	11	1	0	0	1	0	3	6	6	4	1		

		Not at All		Only a Little		Moderately		Much		Very Much			
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*		
How much believe position as teacher in this program enhances ability to carry out typical teaching duties	12	0	0	4	2	2	3	5	6	1	1		
How much believe has something valuable to offer other teachers in this program	12	0	0	2	1	7	6	2	4	1	1		

Table A13. Details of statistically significant Wilcoxon matched pairs tests for 2005-2006 program teacher survey items

Item Focus	*N*	*T*	*Z*	*p*
Extent to which currently able to understand basic engineering concepts	11	0.00	2.20	.028
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering	11	3.50	2.03	.042
Extent to which currently able to enhance content knowledge and understanding of principles of engineering for teachers who teach in a grade between K and 6	11	5.50	2.45	.014
Extent to which currently able to help a student in grade K, 1, or 2 understand how tools and simple machines are used for specific purposes	9	0.00	2.02	.043

Table A14. Response frequencies for statistically significant 2005-2006 program teacher survey items

		Response Frequencies											
		Not at All		Very Poorly		Poorly		Neither Poorly nor Well		Well		Very Well	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Item Focus	***N***	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Extent to which currently able to understand basic engineering concepts	11	1	0	0	0	0	0	2	1	6	3	2	7
Extent to which currently able to teach students in a grade between K and 6 about issues related to engineering	11	1	0	0	0	0	0	4	0	4	6	2	5
Extent to which currently able to enhance content knowledge and understanding of principles of engineering for teachers who teach in a grade between K and 6	11	1	0	0	0	0	0	5	0	4	6	1	5
Extent to which currently able to help a student in grade K, 1, or 2 understand how tools and simple machines are used for specific purposes	9	0	0	0	0	0	0	1	0	5	1	3	8

Table A15. Details of statistically significant Mann-Whitney *U* tests comparing pre-program survey responses for program students (PIEE) and non-program students (Not PIEE) for 2003-2004

	Rank Sum		Valid *N*		*U*	*Z**	*p*
Item Focus	PIEE	Not PIEE	PIEE	Not PIEE			
Interest in rockets and traveling into space	5886.00	4267.00	89	53	1881.00	-2.29	.022
Interest in energy (heat, light, sun)	6114.00	4617.00	92	54	1836.00	-2.83	.005

* Adjusted for ties

Table A16. Details of statistically significant Mann-Whitney *U* tests comparing post-program survey responses for program students (PIEE) and non-program students (Not PIEE) for 2003-2004

Item Focus	Rank Sum		Valid *N*		*U*	*Z**	*p*
	PIEE	Not PIEE	PIEE	Not PIEE			
Interest in tools and building things	6302.00	4576.00	92	55	2024.00	-2.30	.021
Interest in engineering (making things to solve problems, like toasters or bridges)	6148.00	4292.00	92	52	1870.00	-2.50	.012

* Adjusted for ties

Table A17. Details of statistically significant Wilcoxon matched pairs tests for student survey items

Program Year	Item Focus	*N*	*T*	*Z*	*p*
2003-2004	Interest in doing a science project	90	215.00	2.44	.015
2004-2005	Interest in doing a science project	178	635.50	2.55	.011
	Interest in electricity	177	1375.00	1.98	.047
	Interest in engineering (making things to solve problems, like toasters or bridges)	167	1355.00	2.65	.008

Table A18. Response frequencies for statistically significant program student survey items

Program Year	Item Focus	*N*	Response Frequencies					
			Interested		Neither Interested Nor Not Interested		Not Interested	
			Pre	Post	Pre	Post	Pre	Post
		N	*n*	*n*	*n*	*n*	*n*	*n*
2003-2004	Interest in doing a science project	90	68	51	14	27	8	12
2004-2005	Interest in doing a science project	178	143	122	24	36	11	20
	Interest in electricity	177	101	79	48	67	28	31
	Interest in engineering (making things to solve problems, like toasters or bridges)	167	82	105	54	43	31	19

Appendix B

Following are teacher responses to the one qualitative survey item that asked about the extent to which the PIEE program met teacher expectations. These statements reinforce the quantitative findings indicating positive program impact:

- I believe I and my students benefited from having the grad fellow and undergraduates in my classroom.
- I now have a few lessons to include in my science program. Now I stop and think of how I can incorporate engineering concepts into ALL of my science lessons.
- Working on the PIEE Project has enhanced my teaching.
- This was a starting point for us to implement engineering education at the primary level. As a pilot program, I have to say the support of the graduate fellows and undergraduates was very helpful. The units & lesson plans were effective in classroom instruction. Most importantly, the 2nd graders were "turned on" by engineering and the field trip to WPI!
- I thought it was a wonderful program. The children in my classroom loved the program.
- Several students are interested in becoming engineers.
- Very good program. The children benefited from all (high interest positive role models). This program increased my abilities to teach the engineering framework.
- This was an excellent program. It increased my comfort level and ability to incorporate engineering into the curriculum. Also, the students/fellow easily engaged the students. This was a high interest program.
- Indeed! I was able to expand my knowledge of engineering and the lessons created will be valuable in coming years.
- I believe both children and I benefited from knowledge shared. This has given me a great foundation.
- This program has made me a better teacher. I am able to look at a variety of subjects now and approach them from an engineering perspective. The students, 4th graders, have begun to do this also.
- It helped me learn more about engineering and how to integrate engineering concepts into my 3rd grade curriculum
- I enjoyed teaching and learning engineering principles.
- The lessons and activities are realistic, interesting, and fun. PIEE has been a positive experience.
- It was an excellent avenue to strengthen my knowledge of science/engineering concepts and create developmentally appropriate activities to incorporate the engineering frameworks. The partnership with WPI was great! I hope there will be future opportunities.
- The PIEE Program has made me a successful and motivated teacher of engineering. I am very comfortable teaching engineering whereas in the beginning of the program the word

"engineering" alone made me uneasy. Thank you for the PIEE project! The end results were wonderful!

- I learned a tremendous amount. Each Tuesday I grew in many areas along with the children.
- Share a different understanding of engineering. Thank you soooo much for this opportunity.
- I think the grad students and undergrad students worked very hard to develop interesting lessons that incorporated the goals of the MA Science & Technology Engineering Framework into the third grade curriculum. I will enjoy using these lessons for years to come.
- It helped me feel more comfortable presenting the engineering process in class using correct terminology.
- It was a wonderful program and it addressed the frameworks for kindergarten. It was presented at a kindergarten level and the children thoroughly enjoyed it.