AC 2011-2077: THE IMPACT OF PROFESSIONAL DEVELOPMENT ON TEACHERS INTEGRATING ENGINEERING INTO SCIENCE AND MATHEMATICS CLASSROOM

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The Impact of Professional Development on Integrating Engineering into Science and Mathematics Classroom

Introduction

In the executive report to President Barack Obama, *Prepare and Inspire: K-12 education in Science, Technology, Engineering, and Math (STEM) Education for America's Future*[1], the President's Council of Advisors on Science and Technology stated that the education system in the U.S. must prepare students to have a strong foundation in science, technology, engineering and mathematics (STEM). The report concluded that the progress and prosperity of the United States in the future will be dependent on the quality of K-12 STEM education. The congressionally request report, *Rising above the Gathering Storm*[2] also called for a comprehensive, coordinated federal effort to ensure more students join STEM fields and recommends training more qualified teachers to teach STEM education in K-12. The report firmly claimed in order to improve STEM education in K-12, schools need to recruit and maintain qualified teachers in STEM field.

Today, STEM integration is a nationwide movement. Educators are mobilizing at the national and state level to meet the call to increase students' interest and achievement in STEM fields. Many states, such as Minnesota, Texas, Oregon, and Massachusetts, support the STEM education movement by legislated efforts through the addition of engineering standards to the existing science standards[3-4]. These reform documents stress the nexus among science, mathematics, engineering and technology for STEM integration.

In many aspects, engineering has been considered as a bridge to connect STEM subjects together. For example, by providing a gateway turning the abstract science and mathematics concepts into concrete real-life applications[5-6], potentially engineering can act as a catalyst to improve student learning and achievement in science and mathematics[6-9]. On the other hand, building an engineering project can also serve as a pedagogical strategy where to combine problem solving, creative thinking and presentation skills in other STEM subject as well[5-6, 9-11].

Although integrating engineering into science and mathematics teaching and learning has many advantages, engineering rarely receives attention in K-12 classrooms. Many research suggested that the majority of K-12 science and mathematics teachers lack knowledge and experience of engineering, and how to utilize engineering to connect other STEM subjects[12-13]. Therefore, science and mathematics teachers have many difficulties in implementing curriculum that call for the infusion of engineering concepts into their teaching. This may impede the pursuing goal of STEM literacy in K-12 schools in the U.S. Therefore, a call for quality professional development programs to teach more in-depth knowledge of engineering and how to integrate engineering into science, mathematics and technology is in an urgent need. In order to address the need for science and mathematics teachers and better understand how teachers integrate engineering into their teaching, it is important for educators and researchers to understand teachers′ perceptions of engineering and their attitudes toward integrating engineering into their teaching. This paper explores these two aspects in order to provide an overall view of what role engineering plays in K-12 science and mathematics classrooms.

Research Question

The purpose of this research is to explore teachers′ understanding of engineering design and the impact on secondary science and mathematics teachers' attitudes toward integrating engineering into their teaching after a year-long professional development program. The questions that guide this research are as follow:

1) What are science and mathematics teachers′ attitudes of integrating engineering into their teaching after a year long professional development program?
2) What are science and mathematics teachers′ understandings of engineering design after a year long professional development program?

Literature Review

Engineering in K-12

Engineering education in K-12 schools is in its early development. The report, *Engineering in K-12 Education*, recently released by the National Academy of Engineering and National Research Council[6] provided a very insightful view of engineering education in K-12. The report claimed three principles for K-12 engineering education. First, it believed K-12 engineering education should emphasize engineering design. Second, K-12 engineering should incorporate important science, mathematics, and technology concepts and skills. Finally, K-12 engineering should align with 1) systems thinking, 2) creativity, 3) optimism, 4) collaboration, 5) communication, and 6) attention to ethical considerations to promote engineering ″habits of mind″ (pp. 4-6). In summary, the report concluded there is no widespread agreement on what should be taught in K-12 engineering. However, it pointed out that one of the key ideas of engineering that needs to be emphasized in K-12 classrooms is engineering design, which relates to data analysis, constraints, modeling, optimization, trade-offs, and systems. Based on the report, which reviewed the 34 engineering programs, engineering was embedded and interwoven in science, math, and technology.

On the other hand, many research studies suggested that building an engineering project for K-12 requires an interdisciplinary approach, such as knowledge from science, mathematics, and technology[9, 14-15], and also skills related to problem solving, creative thinking and communication[5-6, 10-11]. The existing research studies also suggest integrating engineering into science and mathematics classrooms may benefit students′ learning in science and mathematics[6, 16]. Therefore, giving the importance of teaching engineering in K-12, such as to increase students′ awareness of engineering as a career path, and to bridge science, mathematics, technology and other enabling subjects, it is imperative that K-12 students be given opportunities to practice engineering in their formal education.

Engineering Design

The report, *Engineering in K-12 Education*[6] suggested the first principle to teach engineering in K-12 is engineering design. Engineering design is the process that engineers use to solve engineering problems and to develop products. It also encapsulates the essence of the engineering profession. The report of the T*ask Force on Engineering Analysis and Design*[17] stated, "a problem in design leaves wide latitude for the play of creative imagination and the exercise of judgment in the search for solution." Peterson[18] suggested engineering design is "almost invariably multidisciplinary" (p.531) According to the 2011-2012 *Criteria for Accrediting Engineering Programs*[19], ABET states that engineering design " is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering science are applied to convert resources optimally to meet these stated needs" (p.4). Overall, engineering design has been treated as a pedagogical strategy to bridge science and mathematics concepts in use of solving ill-defined (open-ended) problems, developing creative thinking, formulating solutions and making decisions, and considering alternative solutions to meet a variety of constrains.

A college student, whose major is engineering, spends a good portion of his/her four-year degree learning the ins-and-outs of engineering design. Therefore, in order to adapt engineering design into K-12 sittings, engineering design needs to be simplified to fit the purpose for different programs in K-12. For example, the *Engineering is Elementary* (EiE) curricula by Museum of Science - Boston, which focuses on elementary student learning, feature lessons and learning activities by a simple five step engineering design cycle: ask, imagine, plan, create, and improve[20]. Throughout the STEM integration professional development program, the teachers were introduced to multiple models of the engineering design process. We introduced the EiE design process as well as adapted the engineering design cycle from the *Power of the Wind: How* *can we think like an engineer*[21] by the University of Illinois. This engineering design cycle had eight steps: (1) what is the challenge? (2) How have others solved this?, (3) Brainstorm possible solution: What are the design criteria and constrains?, (4) Which of the possible solutions do you choose? (5) Build prototype, (6) How does it work? Try it and test again, (7) how do you learn from the design of others? and (8) How can you use your new ideas to improve your design? We also used an extremely simple version: express, test, revise[22]. In the final day of training, teachers were provided instruction using the design cycle presented in the *Save the Penguins*[23] curricula, which is an Engineering Teaching Kit. Despite the fact that engineering design has many variations of models, all versions have similar processes, which include cycling between identify the problem, creative thought, analysis, and decision making.

Teachers' beliefs and attitudes of Teaching Engineering

Previous studies argue that teachers' attitudes and beliefs influence teachers' classroom practices in mathematics and science[24-27]. Teachers often fail to develop or implement new curriculum about teaching and learning because of their beliefs that the current educational environments are effective and efficient based on their limited experiences[28]. Teachers' beliefs stem from their own experiences and their educational environments[29]. So, teachers need to have positive attitudes or beliefs about new teaching approaches in order to succeed with the classroom practices. They also need to have various positive experiences to change their current beliefs about teaching that prevent from developing the new teaching approaches. Levitt[25] and Clark & Peterson[30] argued that teachers' beliefs could be strengthened and changed with more experience gained by successful classroom practice or with opportunities for the development of their philosophic beliefs underlying practice. Teachers' beliefs also influence their expectation that they can effectively help student's learn[31-32]. Previous research has provided a strong relationship between teachers' beliefs and students' work habits and academic success[33-34].

However specific to how teachers' beliefs or attitude influence engineering integration into their teaching, research is limited. Some researchers provided evidence that teachers' beliefs, attitudes and expectations toward engineering education relate to teacher's decision-making regarding their instruction practices, such as integrating engineering contexts or contents into teaching science and mathematics[35]. Douglas, Iversen and Kalyandurg[15] conducted a survey study that particularly sought to understand what teachers think of engineering as an academic and career pathway for their students. In the 522 total responses from K-12 teachers to the online survey, the study found teachers believed teaching engineering can be a way to help teach students about business and history. However, there was no evidence in the study to support whether or not teaching engineering can help teach any subject other than business and history.

Although, teachers, who teach science or mathematics, believed that science, mathematics, and engineering are related in a very natural way[36], and engineering education can provide many benefits to students[15], they also believe that engineering is not accessible for a large number of their students, particularly women and minorities[15].

Method

Science, Technology, Engineering and Mathematics integration professional development program (STEM PD) was a five day training that was spread throughout the 2009-2010 school year, with four Professional Learning Community (PLC) sessions between each training day. The participants in the STEM PD were middle and high school mathematics and science teachers. Overall goal for the STEM PD was to provide engineering, science, and technology as contexts to establish a repertoire of developed questioning techniques to help guide student learning in science and mathematics and developing teachers' deeper understanding of the subjects they teach, with a focus on STEM integration. The data collection of the STEM PD involved both formative and summative data collection. The summative data collection focused on measuring teachers' knowledge of the process of science and engineering content. The summative data collection included pre and post *teachers' self-efficacy of teaching science/mathematics within engineering context survey*, and *engineering design cycle survey*. The formative data consists of STEM lesson plans from teachers who were highly interested in implement STEM integration in their teaching. More information about each of the elements of the methods is described in detail below.

STEM Professional Development Program

In 2009, the Minnesota Department of Education funded several professional development programs for teachers to learn about STEM integration. This research was conducted in one of those STEM integration professional development programs. The Secondary STEM integration teacher-training module was a professional development program that provided a STEM integration experience for STEM teachers in grades 6-12. Primarily filled with science and mathematics teachers, the program sought to help science and mathematics teachers to become familiar with the new Minnesota science standards and to encourage the integration of engineering into their science and mathematics teaching. The training provided instructional strategies to aid secondary school teachers in implementing STEM contexts into their classrooms and to increase their understanding of the connection between the areas of STEM. The overall goal of the STEM integration professional development program was to develop teachers′ deeper understanding of the subjects they teach and to explore mechanisms for integration across the STEM disciplines. The professional development program was a five-day training that was spread throughout the 2009-2010 academic year, with Professional Learning Community (PLC) sessions between each training day. The training topics included (1) exploring engineering as a discipline and the engineering design cycle, (2) exploring mathematical connections to engineering design cycles lessons, (3) exploring mathematical thinking through Model-Eliciting Activities[22], (4) technology integration to enhance learning of science, engineering and mathematics, and (5) orchestrating student discussions around STEM concepts. Engineering concepts were focused on the first and second day of training. The facilitators used hands-on activities to connect engineering with science, mathematics and technology. The hands-on learning experience also provided great STEM integration examples that could be used by teachers in their classrooms.

Participants

The participants were secondary science and mathematics teachers. A majority of these teachers taught in urban or suburban public schools. To most of the participants, STEM PD was their first STEM integration professional training program. In total ten schools and seventy-four teachers participated in the program. However, due to various reasons, such as some teachers did not stay the entire training, the pre and post tests for the teachers' *self-efficacy of teaching science/mathematics within engineering context survey* and *engineering design cycle* had different number of participants in this study. A total of twenty-eight mathematics teachers and twenty-four science teachers completed both the pre and post test of the *Teachers' self-efficacy of teaching science/mathematics within engineering context Survey*. On the other hand, twenty-nine mathematics teachers and twenty-six science teachers completed the *Engineering design cycle survey* pre and post test.

Data Collection

Teachers' self-efficacy of teaching science/mathematics within engineering context Survey

The *teachers' self-efficacy of teaching science/mathematics within engineering context* is a Likert-scale survey with the responses strongly disagree, disagree, sometimes agree/sometimes disagree, agree, and strongly agree). The original survey had 25 items that intended to explore teachers' self-efficacy of teaching science/mathematics and underlying perceptions of STEM activities impacted their teaching and student learning. There was a section focused on the value of integrating engineering into science/mathematics. This section included nine items. The purpose of the questions was to investigate teachers' attitude of the integration of engineering into their teaching. Two out of nine survey items were reverse items. However, those two reverse items had typos in them, and the typos caused confusion to participants. Therefore, the two reverse items were dropped from the study. In the end, seven items were analyzed in this study

(Table 1). The coding for the five scales' rating were 1= strongly disagree, 2=disagree, 3=sometimes agree/sometimes disagree, 4= agree, and 5=strongly agree. Each teacher participant was asked to complete the survey during the first day and the last day of the program.

Table 1. The Survey Items of the Teachers' Self-Efficacy of Teaching Science/Mathematics within Engineering Context Survey

Survey items
1. I am comfortable with integrating engineering contexts into my science/mathematics teaching.
2. Integrating engineering helps me teach science/mathematics in a more effective way
3. Integrating engineering helps me to connect science/mathematics to the real-world.
4. Integrating engineering helps me adopt more problem-solving into my teaching.
5. Integrating engineering promotes students' learning and interest in science/mathematics.
6. Integrating engineering makes learning in science/mathematics easier for students who find science/mathematics difficult.
7. I will integrate engineering in my future science/mathematics teaching.

Engineering design cycle survey

The *engineering design cycle* survey was a survey that included an open-ended question. The question was "please describe in words or a diagram the process that engineers use to solve problems." The question intended to elicit participants' understanding of what engineering design cycle is. Each teacher participant was asked to complete the survey during the first day and the last day of the program.

STEM lesson plan

Four Professional Learning Community (PLC) sessions were conducted in between each training day. The PLC activities were highly structured and closely tied to the training days. The PLC session provided an environment to meet together and reflect on what they learned during the training sessions, and to share/learn to implement ideas from the training into their classrooms. Each PLC session required that teachers handed in some documents to the research/teaching team, such as lesson plans and samples of students' artifacts and homework to share their ideas and reflections about STEM integration with other teachers. The second PLC documents particularly focused on integrating engineering into science or mathematics teaching. Therefore, we provide some examples of teachers' lesson plans and reflections in this study.

Data analysis

The paired sample t-test is a statistical technique that used to compare two population means in the case of two samples that are correlated. Generally, it used when measurements are taken from the same subject before and after the treatments[37]. Therefore, to compare the impact of the STEM PD, the paired samples t-test were conducted to analyze the pre and post surveys, *teachers' self-efficacy of teaching science/mathematics within engineering context*.

On the other hand, in order to standardize the answers of the open-ended question in the *Engineering design cycle survey*, a coding framework was used to analyze the answers. Three categories were developed in the coding frame, novice, intermediate, and advanced level (Table 2). After acquiring each survey's standardized score by using the coding framework, the paired sample t-test was conducted to analyze the pre and post test of the *engineering design cycle survey*.

Table 2. The Coding Framework for the Engineering Design Cycle Survey

Score 0	Novice levels (Score 1)	Intermediate levels (Score 2)	Advanced levels (Score 3)
No responses or the answers were incorrect.	The answer included engineering design cycle, but was incomplete. The main steps should be included in the answer (or ideas that were similar) were as follows: 1) define the problem, 2) gather pertinent information, 3) generate multiple solutions, 4) analyze and select a solution, 5) test and implement the solution, 6) re-design/modify products/process.	The answer included each main step of engineering design cycle (or ideas that were similar): 1) define the problem, 2) gather pertinent information, 3) generate multiple solutions, 4) analyze and select a solution, 5) test and implement the solution, 6) re-design/modify products/process.	1. The answer included each main steps of engineering design process. 2. The answer demonstrated the concept that engineering design cycle is a loop. 3. The answer demonstrated concepts of trade off and constraint situations in an engineering design process.

Results

In the *teachers' self-efficacy of teaching science/mathematics within engineering context survey*, besides the first item in the pre-test, math teachers tend to have positive attitudes toward integrating engineering into their teaching in both pre and post test for most of the survey items ($M \geqq 3.5$). This particularly showed in the survey item 3, 4, and 7($M > 4$) (Figure 1).

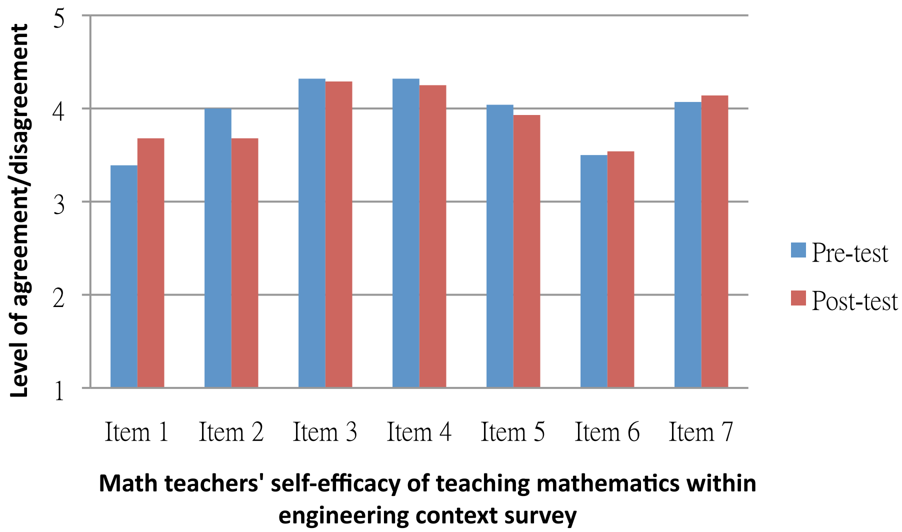

Figure 1. Math Teachers' Mean of Agreement or Disagreement for Each Item (1=strongly disagree, 2=disagree, 3=sometimes agree/sometimes disagree, 4=agree, and 5= strongly agree).

As for science teachers, overall they tend to have positive attitudes toward integrating engineering into their teaching in both pre and post test for all the survey items (M ≧3.5). This particularly showed in the survey item 2, 3, 4, 5 and 7(M >4) (Figure 2).

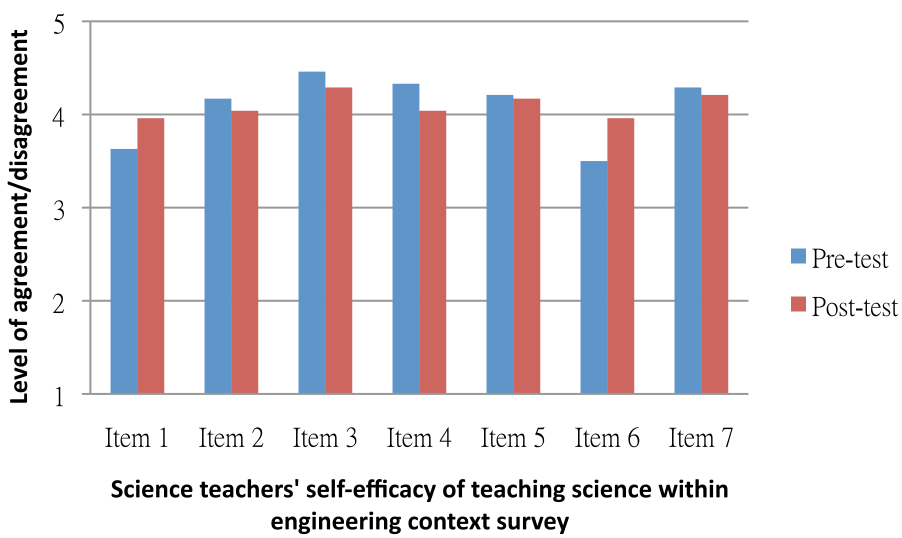

Figure 2. Science Teachers' Mean of Agreement or Disagreement for Each Item (1=strongly disagree, 2=disagree, 3=sometimes agree/sometimes disagree, 4=agree, and 5= strongly agree).

In the paired sample T-test analysis, one item showed significantly different in math teachers. The item was "Integrating engineering helps me teach science/mathematics in a more effective way" (Pre-test: M=4, SD=.39, Post-test: M=3.68, SD=.55, t (27) = 2.78, *p*=.01) (Table 3). This suggested that before the STEM PD, math teachers agreed that integrating engineering could help them teach in a more effective way, but they were not sure about this after the STEM PD.

Table 3. Math Teachers' Summary Result of Paired Sample Test for the *teachers' self-efficacy of teaching science/mathematics within engineering context survey* (*N*=28).   (* P < 0.05)

Survey Items	Mean		SD		t	*p*
	Pre	Post	Pre	Post		
I am comfortable with integrating engineering contexts into my science/mathematics teaching.	3.39	3.68	.99	.86	-1.28	.21
Integrating engineering helps me teach science/mathematics in a more effective way	4.00	3.68	.39	.55	2.78	.01*
Integrating engineering helps me to connect science/mathematics to the real-world.	4.32	4.29	.55	.66	.33	.745
Integrating engineering helps me adopt more problem-solving into my teaching.	4.32	4.25	.48	.59	.49	.63
Integrating engineering promotes students' learning and interest in science/mathematics.	4.04	3.93	.51	.54	.77	.45
Integrating engineering makes learning in science/mathematics easier for students who find science/mathematics difficult.	3.50	3.54	.96	.77	-2.54	.80
I will integrate engineering in my future science/mathematics teaching.	4.07	4.14	.54	.55	-.57	.57

As for science teachers, one item showed significantly different in pre and post test. The item was "integrating engineering makes learning in science/mathematics easier for students who find science/mathematics difficult" (Pre-test: M=3.5, SD=.89, Post-test: M=3.96, SD=.75, t (23) = -2.41, *p*=.024) (Table 4). This indicated that science teachers increased their agreement about integrating engineering helping their students who find science difficult after going through the STEM PD.

Table 4. Science Teachers' Summary Result of Paired Sample Test for the *teachers' self-efficacy of teaching science/mathematics within engineering context survey* (*N*=24) (* P < 0.05)

Survey Items	Mean		SD		t	*p*
	Pre	Post	Pre	Post		
I am comfortable with integrating engineering contexts into my science/mathematics teaching.	3.63	3.96	1.01	.81	-1.78	.09
Integrating engineering helps me teach science/mathematics in a more effective way	4.17	4.04	.64	.86	.83	.42
Integrating engineering helps me to connect science/mathematics to the real-world.	4.46	4.29	.59	.62	1.28	.21
Integrating engineering helps me adopt more problem-solving into my teaching.	4.33	4.04	.76	.91	1.66	.11
Integrating engineering promotes students' learning and interest in science/mathematics.	4.21	4.17	.51	.76	3.27	.77
Integrating engineering makes learning in science/mathematics easier for students who find science/mathematics difficult.	3.50	3.96	.86	.75	-2.41	.02*
I will integrate engineering in my future science/mathematics teaching.	4.29	4.21	.62	.78	.81	.43

As for the *Engineering design cycle survey*, both mathematics (Pre-test: M=1.34, SD=.55, Post-test: M=2.21, SD=.49, t(28)=-7.99, *p*<.001) and science teachers (Pre-test: M=1.62, SD=.57, Post-test: M=2.04, SD=.66, t(25)=-3.10, *p*=.005) showed significant differences in the pre and post tests. This suggested teachers' understanding of the engineering design process increased from the novice level, which could not complete the engineering design process, to intermediate level, which had a complete engineering design process, after the STEM PD. For example, in the pre-test, most teachers could not complete their engineering design process, because the answers that they gave showed no iteration in the manner in which engineers designed. However, in the post-test, most of their answer showed that they had the completed all the basic processes in engineering.

STEM Integration Units and Reflections

Below are descriptions for three examples of STEM integration lesson plans. The first example, packaging engineering, was a collaborative lesson that was implemented by a six grade science and a six grade mathematics teachers. In this lesson unit, the science teacher, Kathy, designed the overall unit plan. The length of her part of the lesson plan was 7 days. Kathy was responsible for teaching science and engineering concepts. The mathematics teacher, Nate, was responsible for teaching mathematics concepts. Nate focused on geometric shapes. His part of the unit was one day long. The major focuses for their lesson plan were: 1) problem solving and inquiry-based teaching, 2) geometric shapes, and 3) engineering design cycle. The engineering challenge in this lesson had students designing an object, such as a box or a bag, to ship stained glass windows to Europe. In Kathy's reflection, she said that her students were struggle looking for information on the internet, but it was fun to see students come up with new, creative ideas and see how students were excited to actually create the box that they wanted. However, the lesson went longer than what Kathy had planned, because students needed more time to complete the project. As for Nick, he was please to know that his students enjoyed the mathematics challenge from a real world problem and students had a sense of autonomy.

The second example, Kite Design, was created by a high school mathematics teacher, Dian. The length of the lesson plan was 7 days and plus a field trip to a historical kite museum. The major focuses of this lesson unit were: 1) scale drawing, 1) coordinate proof of the two different quadrilaterals, 3) history of kits, and 4) the engineering design cycle. The engineering challenge in this lesson had students designing and building a functional kite by using two special quadrilaterals. In her reflection, Dian believed her kids had fun and enjoyed the idea of creating something, and they really loved the idea that they could test their design. However, to her, the lesson took more time than what she had planned, because students needed more time to come up with their own ideas.

The third example, thermal container for an ice cube, was a four days lesson plan. This lesson plan was done by Mary, a six grade science teacher. The focuses for her lesson plan were: 1) engineering design cycle, 2) heat transfer, and 3) testing/evaluation and reflection. The engineering challenge in this lesson was students will design a thermal container for keeping an ice cube from melting for a maximum time period. In her reflection, Mary would like to improve her lesson plan to fit into biology more. She also loved to see how her students were really engaged during the lesson.

Conclusions and Implications

Overall, both science and math teachers had positive attitudes toward integrating engineering into their teaching, even before the STEM PD. However, when comparing science and mathematics teachers, our finding suggests that science teachers have more positive attitudes toward integrating engineering into their teaching. One of the interesting findings was that math teachers agree in the pre-test that integrating engineering makes their teaching more effective. However, in the post-test, their attitudes changed to somewhat agree or disagree. The lesson plan reflections provided possible explanations for this phenomenon. When integrating engineering into science or mathematics, the lesson plan become more student-centered then traditional science or mathematics lesson plans. Students take the lead to design, to plan, and to analyze their work. Students need more time to complete a project or a task in a classroom. Therefore, "an effective way to teach science and mathematics" to teachers may mean a lesson plan that requires less time to implement in their regular class schedule. So for some of the teachers in our study, integrating engineering into science or mathematic may not provide an effective way to teach science or mathematics.

Although in this study, our survey did not show both science and math teachers had changed their self-efficacy of teaching science/mathematics within engineering context after the training program. For several questions, the mean post-test was even lower than mean pre-test. One possible explanation of this is that teachers realized the complexity of engineering. In the beginning of the PD, the teachers viewed engineering as a context, but throughout the training, they learned about how to use engineering design as a means for inquiry. This shift to student-centered teaching caused teachers to initially lower their efficacy around integrating engineering. However, during the course of the PD, the teachers were required to implement engineering design in their classrooms and their comfort level increased. Future studies of our overall data set will explore this phenomena further.

In many aspects the STEM PD had positive impact on both science and mathematics teachers, such as teachers′ understanding of the engineering design process and implementing it in their teaching. After the STEM PD, both science and mathematics teachers improved their understanding of the engineering design cycle. Other data collected from this PD project shows that the teachers developed more concrete ideas about the *Engineering Design Cycle* as a problem solving process in engineering contexts throughout the program [38] Teachers also realized that engineering is not only an interdisciplinary subject, which is connected with other disciplines such as types of engineering (i.e. mechanical engineering, electrical engineering, etc.) and subjects (i.e., science, math, and technology), but also engineering (design process) is related to the cognitive processes of problem solving [38.] The PLC documents show that the engineering design cycle was one of the main focuses to integrate engineering into both science and mathematics classes after the training. Therefore, STEM PD helped teachers see the connection of how to use engineering design cycle in their teaching.

Finally, science teachers agree that integrating engineering made learning in science easier for students who find science difficult. In the PLC documents, teachers suggested that integrating engineering highly engages students. Students enjoyed the design aspects of the lesson plan and also loved testing their own ideas. Fredrickson's "broaden-and-build" theory [39-40] asserts that positive emotions not only build people's momentary experiences in social and physical behavior, but also support intellectual, cognitive and artistic behavior. Therefore, we assumed that high level of engagement could be the key that made teachers believe students who struggle to learn science could do better in their learning by integrating engineering into science. From teachers′ feedback, we also learned that teachers considered some of the disadvantages of integrating engineering into their classroom, such as the need for more time to teach a lesson or unit. Given the findings of our study, we suggest there is a need for more research studies on implementation of engineering in the mathematics and science classroom to understand what is needed for success.

References

1. President's council of advisors on science and technology. (2010). available online at http:///www.whitehouse.gov/ostp/pcast. Last retrieved at Dec. 2010

2. National Academies, Committee on Prospering in the Global Economy of the 21st Century. (2006). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Press.

3. Minnesota academic standards: Science K-12. (2009). Available online at http://education.state.mn.us/mdeprod/groups/Standards/documents/Publication/013906.pdf. Last retrieved at Oct. 2010.

4. National Governors Association. (2007). Innovation America: Building a science, technology, engineering and math agenda. Washington, DC: National Governors Association Center for Best Practices. Retrieved April 14, 2007, from http://www.nga.org/Files/pdf/0702INNOVATIONSTEM.PDF

5. Erwin, B. (1998). K-12 education and systems engineering: A new perspective. Proceedings of the American Society of Engineering Education National Conference, Session 1280: p6, Seattle, WA.

6. Katehi, L., Pearson G., & Feder M. (2009). Engineering in K-12 education: Understanding the status and improving the prospects. Washington, DC: National Academy of Engineering and National Research Council.

7. Akins, L., & Burghardt D. 2006. Work in progress: Improving K-12 mathematics understanding with engineering design projects. P.p 13-14 in Frontiers in education conference, New York. New York: Institute of Electrical and Electronics Engineering.

8. Foutus, D., Dershimer, R.C., Krajcik, J.S., Marx, R.W. & Mamlok-Naaman R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, 41 (10), 1081-1110.

9. Thornburg, D. (2009). Hands and minds: Why engineering is the glue holding STEM together. Thornburg Center for Space Exploration. Retrieved from http://www.tcse-k12.org/pages/hands.pdf.

10. Lewis, T. (2006). Design and inquiry: Bases for an accommodation between science and technology education in the curriculum? J*ournal of Research in Science Teaching*, 43(3), 255-281.

11. Roth, W.M. (2001). Learning science through technological design. *Journal of Research in Science Teaching*, 38(7), 768-790.

12. Cunningham, C., & Knight, M. (2004). Draw an engineering test: Development of a tool to investigate students' ideas about engineers and engineering. Paper presented at the American Society for Engineering Education Annual Conference and Exposition. Salt Lake City, Utah, June 20-23. Available online at http://soa.asee.org/paper/conference/paper-view.cfm?id=19444.

13. Oware, E., Capobianco, B., & Diefes-Dux, H. (2007). Gifted students' perceptions of engineers? A study of students in a summer outreach program. Paper presented at the American Society of Engineering Education Annual Conference and Exposition, Honolulu, Hawaii, June, 24-27. Available online at http://soa.asee.org/paper/conference/paper-view.cfm?id=5401, Last retrieved at Nov. 2010.

14. Brophy, S., Klein, S., Portsmore, M. & Rogers, C. (2008). Advancing engineering education in P-12 classroom. *Journal of Engineering Education*, 97 (3), 369-387.

15. Douglas, J., Iversen, E., & Kalyandurg, C. (2004). Engineering in the K-12 classroom: An analysis of current practices & guidelines for the future. Washington, DC, The American Society for Engineering Education.

16. Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effect of engineering modules on student learning in middle school science classroom. *Journal of Engineering Education*, 95(4), 301.

17. Ver Planck, D.W. (1958). Engineering analysis and design. *The Engineering Science, Report of the Follow-up Committee (ad hoc) on Evaluation of Engineering Education*, ASEE, Washington, D.C.

18. Peterson, C.R. (1990). The desegregation of design. *Engineering Education*, 80, 530-532.

19. ABET. (2010). *Criteria for accrediting programs in engineering*. Baltimore, MA: ABET, Inc.

20. Museum of Science – Boston. (2011). *Engineering is Elementary Curricula.* Accessed online at http://www.mos.org/eie/. Last retrieved January 14, 2011.

21. Office of Mathematics, Science and Technology Education. (2011). *The Power of the Wind Curricula*. University of Illinois. Accessed online at http://wind.mste.illinois.edu/. Last retrieved January 14, 2011.

22. Lesh, R. & Doerr, H. (Eds.). (2003). *Beyond constructivism: Models and modeling perspectives on mathematics problem solving, learning, and teaching*. Mahwah, NJ: Lawrence Erlbaum.

23. Schnittka, C., Bell, R., & Richards, L. (2010). Save the penguins: Teaching the science of heat transfer through engineering design, *Science Scope, 34*(3), 82-91.

24. Handal, B., & Herrington, A. (2003). Mathematical teachers' beliefs and curriculum reform. *Mathematics Education Research Journal, 15*(1), 59-69.

25. Levitt, K. E. (2002). An analysis of elementary teachers' beliefs regarding the teaching and learning of science. *Science Education, 86*(1), 1-22.

26. Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education, 17*(2), 213-226.
27. Wilkins, J. L. M., & Ma, X. (2003). Modeling change in student attitude toward and beliefs about mathematics. *The Journal of Educational Research, 97*(1), 52-63.
28. Mansour, N. (2009). Science teachers' beliefs and practices: Issues, implications and research agenda. *International Journal of Environmental & Science Education, 4*(1), 25-48.
29. Tsai, C. C. (2002). Nested epistemologies: Science teachers' beliefs of teaching, learning and science. *International Journal of Science Education, 24*(8), 771-783.
30. Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. C. Wittrock (Ed.), Handbook of research on teaching. New York: Macmillan.
31. Benner, A. D., & Mistry, R. S. (2007) Congruence of mater and teacher educational expectations and low-income youth's academic competence, Journal of Educational Psychology, 99(1), 140-53
32. Cantrell, P., Velasquez-Bryant, N., Itani, A. & Pekcan, G. (2004). Teachers Integrating Engineering into Science (TIES). In R. Ferdig et al. (Eds.), Proceedings of Society for Information Technology & Teacher Education International Conference 2004 (pp. 4619-4624). Chesapeake, VA: AACE.
33. Fuchs, L. S., Fuchs, D., & Phillips, N. (1994). The relation between teachers' beliefs about the importance of good student work habits, teacher planning, and student achievement. *The Elementary School Journal, 94*(3), 331-345.
34. Rose, J. S., & Medway, F. J. (1981). Measurement of teachers' beliefs in their control over student outcome. *The Journal of Educational Research,* 185-190.
35. Nathan, M. J., Tran, N. A., Atwood, A. K., Prevost, A., & Phelps, A. (2010) Beliefs and expectations about engineering preparation exhibited by high school STEM teachers, *Journal of Engineering Education, 99*(4), 409-425.
36. Wang, Hui H., Moore, T., Roegrig, G., & Park Mi-sun. (In review). STEM integration: Teacher perception and practice. Submitted for review in *The Journal of Pre-College Engineering Education Research*.
37. Agresti, A. & Finlay B. (1997). *Statistical Methods for the Social Science*. Upper Saddle River, NJ: Prentice Hall, Inc.
38 Wang, H. H., Nam Y., Moore T., Roehrig G. (In preparation). *Exploring Secondary Science and Mathematics Teachers' Perceptions of Engineering and Attitude of Integrating Engineering in Teaching*
39. Fredrickson, B. L. (1998). What good are positive emotions? *Review of General Psychiatry*, 2, 300-319.
40. Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, 56, 218-226.