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S. Selcen Guzey

Kristina Tank

Hui-Hui Wang

Gillian Roehrig

Tamara J. Moore
Purdue University, tamara@purdue.edu

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A High-Quality Professional Development for Teachers of Grades 3-6 for Implementing Engineering into Classrooms

S. Selcen Guzey, Kristina Tank, Hui-Hui Wang, Gillian Roehrig, and Tamara Moore

STEM Education Center, University of Minnesota, St. Paul, MN 55108

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Abstract

With the increasing emphasis on integrating engineering into K-12 classrooms to help meet the needs of our complex and multidisciplinary society, there is an urgent need to investigate teachers' engineering-focused professional development experiences as they relate to teacher learning, implementation and student achievement. This study addresses this need by examining the effects of a professional development program focused on engineering integration, and how teachers chose to implement engineering in their classrooms as a result of the professional development. 198 teachers in grades 3-6 from 43 schools in 17 districts participated in a yearlong professional development program designed to help integrate the new state science standards, with a focus on Engineering, into their teaching. Lesson plans and student artifacts were used to assess teachers' engineering practices and the implementation in their classrooms. Results indicated that the majority of the teachers who participated in the professional development were able to effectively implement engineering design lessons in their classrooms suggesting that the teachers' success in implementing high-quality engineering lessons in their classroom was closely related to the structure of the professional development program.

A High-Quality Professional Development for Teachers of Grades 3-6 for Implementing Engineering into Classrooms

K-12 engineering education is at the forefront of reforms in Science, Technology, Engineering, and Mathematics (STEM) education. The recently published *Framework for K-12 Science Education* (National Research Council [NRC], 2012) highlights the role of engineering through both the practices of science and engineering and disciplinary core ideas; the fourth disciplinary core is engineering, technology, and applications of science. The Framework authors stress the "emphasis on scientific and engineering practices and their integration with the core concepts" (NRC, 2012, p. 316). The goal is not the addition of engineering practices but the integration of engineering practices.

The integration of engineering is already happening at the state level with 41 states including engineering into their academic state standards to varying extents (Carr, Bennett & Strobel, 2012). Engineering practices are rapidly making their way into elementary classrooms across the country. However, as few elementary teachers feel adequately prepared or comfortable teaching science (Marx & Harris, 2006; Sandall, 2003), it is even more overwhelming for elementary teachers to additionally think about integrating engineering (Brophy, Klein, Portsmore, & Rogers, 2008; Cunningham, 2008). Due to diminished instructional time for science, increasing accountability pressures, increasing student diversity, lack of science content knowledge, and lack of available resources, we have not yet seen the wide-spread implementation of high-quality science instruction that was identified in previous educational reform documents (Marx & Harris, 2006). It is clear that "while the introduction of engineering education into P-12 classrooms presents a number of opportunities for STEM learning, it also raises issues regarding teacher knowledge and professional development, and institutional

challenges such as curricular standards and high-stakes assessments" (Brophy et al., 2008, p. 369). Elementary teachers, who already face many challenges in their teaching, are now additionally required to integrate and use engineering in the teaching, learning, and assessment of their content.

Clearly, the intentions of the new Frameworks document (NRC, 2012) will not lead to improvements in K-12 science education without the development of professional learning opportunities for teachers, new curriculum, and assessments. Unfortunately, the research on professional development for implementing engineering at the elementary level is very limited and tends to focus on development and implementation related to specific curriculum (NRC, 2009). Yet, without systematic professional development for elementary teachers who are required to integrate engineering into their science instruction, the possibilities and promise of these new national and state standards will not be fulfilled (Roehrig, Moore, Wang, & Park, 2012). Thus, there is an urgent need to investigate teachers' engineering-focused professional development experiences as they relate to teacher learning, implementation and student achievement. The following research question guided our exploration of elementary teachers' experiences integrating engineering into their science curriculum:

- What approaches to engineering integration do teachers in grades 3-6 use after participating in a professional development for engineering integration?

A Brief History of Engineering Education in the National Education Reforms

In recognizing that there has been an increasing emphasis on the addition of engineering in K-12 education, it is important to examine how engineering has been situated in recent reform efforts. In 2009, the NRC released a report titled *Engineering in K–12 Education: Understanding the Status and Improving the Prospect*, a large national study that examined the scope and nature

of engineering education in the United States. This report highlighted the increased presence of engineering in K-12 classrooms and the findings suggest that there is "considerable potential value related to student motivation and achievement" (p. 150) through the inclusion of engineering in K-12 schools. Additionally, the report outlined important components of K-12 engineering: emphasize engineering design; incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills; and promote engineering habits of mind which include skills such as systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations.

While the 2009 NRC report on engineering education included central elements of engineering for K-12 education, specific engineering standards were not identified. The National Academy of Engineering (NAE) report *Standards for K-12 Engineering Education* addressed that, while it is feasible to develop K-12 standards, "it would be extremely difficult to ensure their usefulness and effective implementation" (NAE, 2010, p. 1). The committee of the report was opposed to the development of separate K-12 engineering standards due to various barriers, such as inadequate number of teachers qualified to implement engineering. Instead, the committee offered two strategies for K-12 engineering education: (a) the infusion approach – embedding relevant engineering learning goals into standards for another discipline (e.g., science), and (b) the mapping approach – integrating big ideas in engineering onto current standards in other disciplines. Both strategies address the importance of engineering design, making connections between engineering and other STEM disciplines, and communication.

The Framework for K-12 Science Education (NRC, 2012) aligns with the recommendations from the *Engineering in K–12 Education* (NRC, 2009*)* and *Standards for K-12 Engineering Education* (NAE, 2010). When looking more closely at how engineering is

integrated for K-12 students, key practices were identified in the Framework document as important aspects of science and engineering that should be a central part of K-12 science and engineering curriculum. The Framework authors emphasized that "every science unit or engineering design project must have as one of its goals the development of student understanding of at least one disciplinary core idea" (NRC, 2012, p. 201). Thus, students should learn about science through actually doing science and engineering.

After years of continuing efforts by policy makers and educators to integrate engineering into K-12 classrooms, significant progress has been made in including engineering in existing national and state-level education standards. Several states (e.g., Massachusetts and Minnesota) have even included engineering in statewide high-stakes assessments. However, in contrast to science and mathematics, which have established education standards and state-level assessments, engineering in K-12 education is still very much a work in progress (NRC, 2009).

The Framework of the Study

While there has been an increasing effort to integrate engineering in K-12 education over the past decade, teaching science through engineering design challenges is still rare. Several K-12 engineering design curriculum units have been developed with the goal that students use an iterative design process and apply science content knowledge in complex problem solving activities (Fortus, Dershimer, Krajcik, Marx, & Momlok-Naaman, 2004; Kolodner et al., 2003; Penner, Lehrer, & Schauble, 1998; Roth, 1996). While these engineering curriculum units present some substantial differences, all share several common features such as engineering design.

In a previous study, Moore, Stohlmann, Wang, Tank, & Roehrig (in press) conducted extensive reviews of the research literature on K-12 engineering education and curricular

materials to develop a framework that identifies the elements of quality-engineering design curriculum units. According to the framework, an engineering curriculum unit should: (a) have a meaningful purpose and an engaging context, (b) have learners participate in an engineering design challenge for a compelling purpose that involves problem-solving skills and ties to context, (c) allow learners to learn more from failure and then have the opportunity to redesign, (d) include appropriate science and/or mathematics content, (e) teach content with student-centered pedagogies, and (f) promote communication skills and teamwork.

The presence of a meaningful purpose and realistic, engaging context is critical to engage students and motivate learning. Each engineering lesson should have a clear purpose, which includes explicit engineering learning goals and objectives. A clear purpose helps students know what problems they are addressing in order to facilitate learning and how that promotes the integration of STEM disciplines in order to solve the engineering problem(s) posed by the teacher. A realistic context should connect to students' everyday life experiences as well as help them see how engineering can help people. Setting an engineering lesson in a realistic context engages and motivates students to apply their learning to real-world problems (Brophy et al., 2008; Carlson & Sullivan, 2004). It also highlights the fact that engineers almost always work for a client, and therefore, their problems and solutions are intentional in that they are addressing the needs of that client (Dym, Agogino, Eris, Frey, & Leifer, 2005).

Engineering design is a central tenant of engineering practices and a crucial component of engineering activities (Dym, 1999). As in the case of science where there exists no single scientific method, engineers employ multiple approaches and no single engineering design cycle exists. However, while design processes may be described in many forms, there are fundamental characteristics central to engineering design: (a) problem and background, (b) plan and

implement, and (c) test and evaluate (Moore et al., 2013). The problem and background stage includes the formulation or identification of an engineering problem and researching the problem or participating in additional science activities to gain necessary background knowledge. The plan and implement stage involves brainstorming, developing solution possibilities, evaluating the pros and cons of competing solutions, and creating a prototype, model, or other product. The test and evaluate stage includes testing the prototype and designing experiments to test and evaluate the prototype or solution. Since engineers learn from failure students participating in engineering activities should have opportunities to design, test, and redesign (Dym et al., 2005; NRC, 2009; Wood, Jensen, Bezdek, & Otto, 2001). Thus it is important as part of the design process that students use data from their initial prototype testing to inform the improvements necessary for their redesign.

Including appropriate science and mathematics content is necessary because science and/or mathematics connections in an engineering activity can help students to design better engineering products and outcomes (Kolodner et al., 2003; Penner et al., 1998). Without science and mathematics connections, engineering activities can become isolated, unrelated activities that depict engineering as tinkering or craft projects. In addition, engineering design projects with explicit connections to science and/or mathematics content can increase retention and deepen understanding of content knowledge (NRC, 2009).

Finally, a focus on student learning must be present. Student-centered pedagogies should be used to teach the content and processes in any learning activity since students learn better when they are actively engaged in their learning (Bransford, Brown, & Cocking, 2000). Student-centered pedagogies include having students work in teams and communicate their understandings. Furthermore, these practices represent the work of engineers in the real world;

thus, the engineering activities should allow students to work in teams and communicate their procedures and solutions with others (Dym et al., 2005; NRC, 2009).

The Professional Development Program

In response to new mathematics and science standards, the Minnesota Department of Education funded several regional Mathematics and Science Teacher Partnerships (MSTP) to provide professional development for science and mathematics teachers across the state. The Region 11 MSTP serves teachers from the metropolitan and surrounding area of Minneapolis-St. Paul. Over 1600 elementary, secondary mathematics and secondary science teachers have participated in one or more of the professional development opportunities that the partnership has offered since 2008. Each year, the Region 11 MSTP provides professional development with a different grade and subject-matter focus for both science and mathematics teachers.

The participants in this study were 198 upper elementary and lower middle school teachers (grades 3-6) who took part in the 2010-2011 MSTP science professional development. The research literature on effective professional development was used to guide the development of this year-long professional development with the inclusion of 30 hours of face-to-face professional development (5 full days spread across the academic year) and school-based professional learning community meetings in between workshop days (16 hours) (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2009). The focus of the professional development was to assist elementary teachers in embedding the nature of science and engineering into the teaching, learning, and assessment of science content. Given that engineering is a new addition to the Minnesota Science Standards, the emphasis on engineering and engineering design was the central to the focus of the professional development workshops.

Face-to-Face Workshops

The face-to-face workshops were designed to actively introduce teachers to the new standards in the Nature of Science and Engineering strand and to investigate ways of integrating scientific and engineering practices into their content instruction. The focus of days 1 and 2 was on engineering and engineering design. Nature of science, inquiry, and engineering were the focus of days 3 and 4 and engineering and modeling were the main topics for day 5. Since the overarching goal was to help teachers to better integrate these topics into science instruction, there was an intentional tie between science and engineering in each of the workshops. Table 1 shows the general overview of the face-to-face workshops. Sixth grade teachers could be based in an elementary or middle school and so two different workshops were offered to provide a focus specific to the teachers in each of these school settings. Since the focus of this paper is on the engineering integration, only those aspects of the professional development will be explained in detail in the following sections.

[Insert Table 1 about here]

During the day 1 workshop, teachers explored the question, "What is Engineering?" by looking at their own misconceptions as well as potential student misconceptions. The workshop started by having teachers individually participate in the Draw an Engineer Test (Knight & Cunningham, 2004). In small groups, teachers developed concept maps to represent their knowledge of and understanding about engineering. Small groups presented their concept maps to the whole group and then a discussion was held about the similarities and differences among the concept maps created by the teachers. Afterwards, teachers experienced an Engineering Teaching Kit (ETK) unit on heat transfer (*Save the Penguins*) that integrates engineering design with the scientific concepts of heat transfer while using an engaging and realistic context (Schnittka, Bell & Richards, 2010). This unit was presented as a quality-engineering unit since it

has all the elements of the quality-engineering curriculum framework (Moore et al., in press). *Save the Penguins* activities use the context of global warming: Rising temperatures and melting ice have affected penguin habitats. Playing the role of students during the Save the Penguins activities, teachers developed their conceptual understanding of conduction, convection, and radiation through a series of discrepant events and inquiry activities. Teachers then applied their knowledge of heat transfer to an engineering design challenge that asked them to design a shelter from everyday materials to protect their ice-cube penguin in an oven (plastic box with a black bottom and sides covered by aluminum foil that was heated by three heat lamps). Teachers worked in teams and they followed an engineering design process while developing their shelters. They also had the opportunity to redesign their shelters.

Elementary teachers continued their exploration into engineering and engineering design during the second day workshop using examples from the EiE curriculum (http://www.mos.org/eie/) to introduce teachers to other examples of engineering curriculum and to highlight how this engineering curriculum could be integrated with science instruction. During the day 2 workshop, teachers reviewed the components of engineering design before they explored the field of bioengineering as they designed and built model membranes. The instructors introduced the engineering design challenge, which was to design a model membrane for an imaginary pet frog to find a way to make sure it gets enough water. Teachers then tested materials that they would be using in their engineering design challenge. Afterwards, the instructors introduced the science concepts such as the structure and function of membranes to help teachers increase their understanding of the science content. The teachers worked through the engineering design challenge and then evaluated and presented their results before improving their original design.

Day 3 of the workshop focused on the similarities and differences of engineering and science as an introduction to the nature of science. The morning activities focused on (a) theories, hypothesis, and laws, (b) observation versus inference, creativity and tentativeness, (c) black box activities, (d) subjectivity and social and cultural context (Bell, 2008) and the afternoon activities focused on inquiry-based pedagogies with properties of light as the content. The day concluded with an engineering extension having teachers apply the content learned about light to reverse engineer a pinhole camera. Day 4 of the workshop started with exploring magnets through inquiry activities. Afterwards, the *Cleaning an Oil Spill* unit from EiE was used to help teachers to see how they could use inquiry and engineering during their science instruction. Teachers used the engineering design cycle to create a process for cleaning an oil spill so that the oil had the least impact on the surrounding ecosystem. Playing the role of students during the *Oil Spill* activities, teachers also developed their understanding of an ecosystem and its components and their relationships.

Sixth grade teachers who taught in middle school settings had a common experience on day 1 (the Save the Penguins curriculum) and day 3 (nature of science/light), but different workshops on days 2 and 4 that were more focused on the physical science content that they would be responsible for teaching. During day 2, teachers experienced an engineering design cycle to design, build, and test a variety of blade designs in order to maximize the power output of a table-top wind turbine. Teachers also explored topics such us energy conversion, energy resources, and wind energy. Day 4 was dedicated to force and motion and six grade teachers used Vernier Lab Probes to collect and analyze data. Teachers created and interpreted graphs (i.e., velocity vs. time, distance vs. time) and built rubber-band cars following engineering design cycle with the purpose of designing a car that travelled faster and further.

Professional Learning Communities (PLC)

Teachers participated in PLCs between each of the workshops to reinforce what they had learned and to develop a professional learning culture in their schools (Loucks-Horsley et al., 2009). As schools participated as a team, the number of teachers in each PLC group varied from 6 to 15 for a total of 25 PLCs, each with a teacher assigned as the PLC facilitator. The facilitators participated in a meeting prior to the workshops to learn how to lead meaningful discussions and prepare PLC reports, which included summaries of the activities of each PLC, lesson plans, and student assessments and artifacts.

PLC-A was completed at the school site between the day 1 and day 2 workshops. As part of PLC-A, teachers explored students' conceptions of engineering by assessing student knowledge on engineering before and after they implemented an engineering lesson. Teachers used student assessment protocols from the *What is Engineering* and *What is Technology* assessments from the EiE curriculum. These assessments were designed to help teachers determine what students knew about engineering and technology and how the implementation of engineering activities impacted their students' knowledge about these topics. In each of the 16 picture assessments, students were asked to circle items that are engineering or technology and to write a definition of what an engineer is and how they know if something is technology.

PLC-B was completed after the day 2 workshop in which teachers individually, or in teams, were asked to implement an engineering design activity in their classroom. Each teacher collected 5-10 student artifacts (e.g., drawings, pictures and verbal statements of students' engineering design) and reflected on the engineering design lesson before sharing with the members of their PLC. PLC leaders collected the lesson plans and student artifacts to discuss during the PLC meetings and share with teachers from other schools during day 3 workshop.

Discussions about student work focused on how to use student artifacts to learn student understanding about engineering and to make effective instructional decisions.

PLC-C focused on the nature of science and had no engineering content. The purpose of PLC-D was for the teachers to reflect on their implementation of the Nature of Science and Engineering standards in their classrooms. During the PLC-D meetings, teachers determined teams for the posters and topics to present on the final workshop day. Each PLC created 1 to 4 posters based on the number of participants in their group, usually in grade level teams.

The Study

This qualitative research study followed Yin's (2003) embedded-single case study approach to investigate teachers' engineering practices as they participated in a professional development program. In this case study, the case and main unit of analysis was the professional development as a whole and the smaller, embedded unit of analysis was the engineering lessons that teachers implemented as a result of participating in the MSTP professional development. 198 teachers from 43 schools in 17 districts participated in the professional development program. Table 2 provides details regarding the number of teachers in each grade-level.

[Insert Table 2 about here]

Data Collection

The primary data sources that were used for this study included the team posters from PLC-D of their classroom implementations, and the lesson plans and student artifacts collected as part of the PLC-B assignment. In teams, teachers created the posters as a way to share their classroom activities with other participants during the fifth and final workshop day. 66 posters that included lesson plans, student artifacts, and pictures from lessons were shared during the final poster session. Posters were electronically captured for later analysis. Lesson plans, student

artifacts and pictures collected from PLC-B reports were sent electronically by the PLC facilitators. These data provided insight into lesson implementation and presented additional evidence regarding teachers' implementation of engineering in their classrooms.

Data Analysis

66 posters and 25 PLC-B reports that contained 108 lessons were collected for data analysis. Teachers had a choice to highlight engineering design or nature of science (or both) on their final posters. As the focus of the present study was on the implementation of engineering lessons, the 17 lessons that focused on the nature of science were eliminated from the data. Additionally, there were 14 lessons that could not be categorized, mostly due to missing parts of lesson plans. These 14 lessons were also eliminated from the data to avoid misrepresentation of these lessons. Thus, of the 108 engineering lessons, a total of 77 were coded and categorized.

The first round of data analysis included determining the initial codes as indicators of quality engineering activities. These codes were: purpose, context, engineering design, and science connections. The engineering design code was broken down into four sub-codes: background and planning, building, testing and improving or redesigning. See Table 3 for description of the codes. The codes are closely aligned with framework of the study. The elements, student-centered pedagogy and teamwork from the framework were not used as codes since the lesson plans demonstrated the use of those strategies by all the teachers. Individually, the researchers looked systematically for those codes in the data sources. Following discussions of these predetermined codes and how they represent the data the research team determined that these codes would be sufficient to demonstrate quality-engineering lessons.

[Insert Table 3 about here]

Once the codes were established, three members of the research team individually coded each of the 77 lessons from the posters and came to consensus through discussion when disagreement arose. After the researchers coded the engineering lessons they were categorized by their adherence to the coding framework. The engineering lessons were categorized as complete engineering lesson, design-focused engineering lesson without a realistic context, design-focused engineering lesson without re-design, build and test only lesson, or misapplication lesson (see Table 4).

[Insert Table 4 about here]

Findings

The purpose of the study was to understand the approaches to engineering integration that teachers employed in their elementary and middle school classrooms as a result of their participation in a year-long professional development program. Engineering lessons from the final posters and PLC-B were used to explore teachers' engineering integration classroom practices. Since the majority of the teachers worked in teams to design the engineering lessons, each individual lesson is not a reflection of only one teacher's understanding. Each of the four major categories of engineering integration practices is described in the following section.

Complete Engineering Lessons

Thirty-six lessons (47%) represented complete engineering lessons. Of the thirty-six, twenty-eight of the complete engineering lessons were from published K-12 engineering curricula. For example, *Water, Water Everywhere: Designing Water Filters* and *A Slick Solution: Oil Spill Cleanup* from EiE, wind turbine activities from Kid Wind (http://learn.kidwind.org/), and *Save the Penguins* (Schnittka et al., 2010), were lessons that were modeled during the workshops and subsequently widely used by the teachers.

The remaining eight lessons in this group were developed by the teachers and often adapted from online sources. For example, one 6th grade science teacher collaborated with a mathematics teacher to modify and develop a *paper airplane activity*. While the mathematics teacher addressed content related to calculating surface area of different shapes and graphing and analyzing data, the science teacher addressed content related to aerodynamic forces, Bernoulli's Principle, and experimental design (identifying hypothesis, variables etc.) during the two week-long activity. Students worked in teams and completed several short student-centered activities before the engineering challenge. First, students worked with four different designs of paper airplanes and identified variables that affected the accuracy for flying straight, the distance traveled, and hang time in the air. Students made surface area measurements of the model paper airplanes and graphed their data. Then, the teachers introduced the engineering challenge and set up the engaging context:

> You work for a publishing company. Your team's job is to investigate paper airplane model designs for a new book on folding paper airplanes. Your team may also design your own models for testing. Your part of the book focuses on accurate gliders. The designs chosen for the book are based upon your recommendation which will be determined by accurate and analytical testing. You will report your conclusion using data, graphs, and other criteria in a power point presentation to your supervisors.

Each student team received one sheet of paper and 5 cm of tape to design an airplane to solve the engineering challenge. Students tested their design in the hallway, collected data, and made graphs to analyze their data. The teachers provided with enough time for students to redesign their paper airplane based on their data analysis.

Another example activity was called *Lunar Rover*, where students were challenged to design, build, and analyze a lunar rover model that was powered by a rubber band and had a wheel design that could travel over three different surfaces as well as up an incline. The teacher integrated this engineering activity into the science unit that covered force, motion, and energy. Students first learned the necessary science content and then completed the engineering challenge. Afterwards, students built their first design and calculated speed and acceleration of their initial design and graphed their data. Based on their findings, they then modified their design. This activity was adapted from National Aeronautics and Space Administration's (NASA) Lunar Roving Vehicle activity.

Design-Focused Engineering Lessons without a Realistic Context

This group included 7 lessons (10%). While these 7 lessons allowed students to experience a complete design cycle following exploration of the target science concepts, they did not provide a realistic context for the engineering challenge. In these lessons, teachers often introduced the challenge as a stand-alone problem without highlighting a real-world context for students. Following the presentation of the challenge, the teachers presented a series of steps for students to follow in order to solve the problem. These steps were often listed down the side of a page of paper following the statement of the problem. An example of missing context could be seen in the *Puff Mobile* lesson, where students were asked to design a vehicle out of straws, Lifesavers, paper, and tape that would moved by having the students blow or "puff" on them and they wanted their design to be the first to the finish line. This specific lesson was missing the context for why the students might need to design a car that would need to be moved by "puffing" or wind. This lesson could have been turned into a complete engineering lesson by

including a context such as a need to design a puff mobile for an imaginary client who builds racecars that are powered by air.

Design-Focused Engineering Lessons without Re-Design

These 10 lessons (12%) did not include the redesign phase of the design cycle. In these lessons, the teachers did not ask students to re-design or even provide time to discuss how students might modify their design or product to make it better. For example, in an *Egg Drop* activity students were asked to design packaging for an egg through using a variety of materials. The teacher introduced the challenge using a realistic context. He told students about his experiences with dropping a carton of eggs when carrying groceries home from the store or when removing the carton from the refrigerator. In this lesson, students were asked to answer the following question: how can you design a protection device to protect your egg when you drop it from a certain height? After learning about gravity and drag students started to work in teams to plan out what materials they wanted to use for the egg protection design and to draw the plan for their protection device. After planning, students built and tested their devices. The teacher, however, did not provide time for the students to discuss the possible changes that students would have made if given the opportunity to redesign, rebuild and retest their protection device.

Another example of a lesson that was missing the crucial step of re-design, was the *Junk Jallopy* lesson, which required students to build balloon-powered cars from a collection of "junk" to help NASA's engineers to build a nanorover. This lesson was explicitly designed to target students' knowledge about force and motion. The constraint for their design was that the balloon-powered car needed to have three wheels and may not leave the ground. Students built their car and then had a contest at the end to find which designs met the specified criteria. While this lesson allowed students the opportunity to integrate science content and experience several

of the engineering design cycle components (e.g., ask, plan), students were not asked to redesign their car at the end of the contest. This lesson could have been improved if the teacher had asked students to redesign their original prototype.

Build and Test Only Lessons

13 lessons (17%) were included in this category. These lessons did not follow the steps of an engineering design cycle, rather all the lessons in this category simply included building products such as bridges, toys, or listening devices without including the following components of quality engineering lessons: the identification of a problem, science connections, planning, background testing, and re-design. These lessons focused only on building and testing the product. A *Bridge Building* lesson was an example of this type of lesson, where students were given a variety of materials to build paper bridges and then asked to test how much weight the bridges could hold before breaking. In another example, the students were asked to build a device that could enhance their hearing ability. In this lesson, students were introduced to the test for enhanced hearing, which involved a student dropping a coin in several locations in the classroom while a blind-folded listener tried to find the location. Students then had the opportunity to build a hearing device using paper cup, paper towel roll, or paper plates. One serious issue with these activities is that no science was needed to complete these projects, nor did the students have to meaningfully plan for their designs. Therefore, these activities represent tinkering, not engineering design. These lessons could have been turned into a complete engineering lesson by including a realistic context and purpose, using the science to inform their design, and tying in the planning, testing, and redesign.

Misapplication Lessons

This category includes 11 lessons (14%) and the majority of the lessons in this category were science activities that teachers tried to convert into engineering activities. The specific PLC-B instructions were for the teachers to implement an engineering design lesson that followed an engineering design process, but many of these lessons used "design" in terms of its colloquial definition. For example, two lessons included designing a healthy menu and designing a skeleton. In the designing a healthy menu lesson, students evaluated their own diets and learned how to incorporate healthy foods into their daily meals and snacks. First, they kept a food diary and after class discussions on healthy menus, they created their own healthy menus.

Other lessons in this category were common science experiments such as the Diet Coke and Mentos "challenge" that the teachers incorrectly categorized as an engineering activity. In the Diet Coke and Mentos experiment, students dropped different numbers of Mentos into a Diet Coke bottle and measured how high diet coke reached following the chemical reaction. While, this is an engaging science activity that could allow students to investigate chemical reactions and manipulate variables and experimental design, it is not an engineering activity.

Conclusion

The majority of the engineering lessons that were implemented by the teachers who participated in the Region 11 MSTP professional development were either complete engineering lessons or design-focused engineering lessons with a missing component. While the complete lessons include a realistic context, lesson purpose, engineering design, and science connections, lessons in the latter group were missing either a realistic context or the redesign step of the engineering design process. The absence of a realistic context was identified in 7 engineering lessons. The use of a realistic context is critical in order to place engineering problems into a situation explaining why students or engineers might need to solve similar problems. Setting an

engineering lesson in a realistic context also allows students to meaningfully interpret the engineering problem (Brophy et al., 2008; Carlson & Sullivan, 2004; Moore, 2008). A realistic context can be also used as a vehicle to enhance student motivation to solve engineering problems or challenges.

Redesign allows students to reflect on their original designs and make or suggest improvements (Kolodner et al., 2003). This step is important for highlighting the iterative nature of the engineering design (NRC, 2009; 2012) and promotes the idea that failure is acceptable in the field of engineering (NRC, 2012). Learning from failure is critical for engineers so that future product development and design can be more successful. Likewise, recognizing failures and learning from failures allows students to identify what they should have done differently.

In addition to including a realistic context and re-design, the integration or application of science knowledge is critical for a quality-engineering lesson. For example, 13 build and test only lessons did not allow students to apply appropriate and/or adequate science knowledge and were therefore missing natural connections and opportunities to integrate multiple subjects into their engineering challenges. While science can be a great opportunity to support engineering design activities, it has also been suggested that a potential benefit to implementing engineering is an improvement in student achievement and motivation in science (NRC, 2009). One of the benefits to engineering is that it requires the application of mathematics and science content and skills in the creation of a product or process (Brophy et al., 2008; NRC, 2012).

Discussion and Implications

National reforms have asked science teachers to integrate engineering into instruction (NAE, 2010; NRC, 2009, 2012). The process of engineering integration into science classrooms is difficult and complex, thus reform efforts must address the issue of professional development

for science teachers for quality engineering integration. This study provided a detailed description of an engineering integration professional development for upper elementary and lower middle school science teachers and explored the effects of the program on teachers' engineering integration approaches. The quality engineering education framework developed by Moore et al. (in press) guided the design of the Region 11 MSTP program and the research study.

Engineering integration is difficult for science teachers for several reasons. First, few teachers are knowledgeable about or comfortable with using engineering design as a vehicle to teach content (NAE, 2010). Professional development opportunities for engineering integration are few (NRC, 2009); however, programs like Region 11 MSTP can provide a variety of experiences for teachers to attain knowledge and skills necessary to successfully integrate engineering into teaching. Second, many teachers think engineering is just another addition to their heavily loaded science curriculum. However, engineering can be used as a context to teach science and students can apply science knowledge and scientific reasoning to solve engineering design challenges (Fortus et al., 2004; Kolodner, et al., 2003; NRC, 2012; Penner et al., 1998). A majority of the teachers in this study used engineering as a context to teach science instead of teaching engineering as an additional content.

Third, it is challenging to teach all science concepts through engineering design challenges. As also demonstrated by the sample lesson plans from our study, many of the engineering design challenges involve in physical science concepts such as force and motion, and simple machines. It is harder to find engineering challenges in which students investigate life science or biology concepts. There are only a few notable exceptions: a couple of EiE units (e.g., designing model membranes) and designing human elbow unit from Penner, Lehrer and

Schauble (1998). Finally, many science teachers struggle with the time constraints and implementing some of the available engineering design units, which take 5-10 class periods. For example, each EiE unit includes four lesson plans that last one to two weeks. As found in our data, skipping the re-design part of the engineering challenge is one common strategy used by teachers to decrease the amount of time spent on engineering design challenges. However, re-design is a critical component of engineering design and helps students to understand the iterative design process (Dym et al., 2005; Moore et al., 2013; NRC, 2009; Wood et al., 2001), as well as learn from failure.

Professional development is needed to explicitly assist teachers with recognizing and implementing quality engineering integration. The committee on K-12 Engineering Education (NRC, 2009) found as an advantage of a well-designed professional development is that "teachers come away with in-depth understanding of the purpose of the materials and first-hand experience with some of the difficulties and successes students might encounter" (p.103). Research would also be necessary to develop and evaluate approaches to teacher professional development. There is much that can be learned from looking at the Region 11 MSTP and how our teachers implemented engineering into their grade 3-6 classrooms and the effects of the professional development program on this implementation. Furthermore, the professional development program and the findings of the study would also provide guidelines for pre-service teacher educators on how to introduce engineering integration in teacher preparation programs so that pre-service teachers start developing their engineering practices early on. As engineering education continues to make its way into K-12 classrooms, it is important to ensure that we are preparing and developing high quality teachers in STEM fields.

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Table 1

Topics for Face-to-Face Workshops

Topic	Dates	Content	Science and Engineering Standards Addressed
Day 1: Engineering	Sept.	What is engineering?	Practices of engineering
		Heat transfer: Save the Penguins (Schnittka, Bell, & Richards, 2010).	Transfers of heat energy
Day 2: Engineering Design	Nov.	Engineering Design Cycle	Practices of engineering
		Just Passing Through: Designing Model Membranes (EiE Unit)	Interdependence among living systems
		Wind Turbine Design (6th grade middle school teachers only) (http://learn.kidwind.org/)	Changes in energy forms
Day 3: NOS, Inquiry and Engineering	Jan.	NOS Activities: Observation vs. Inference, Scientific Theories vs. Laws, Creativity and Subjectivity in Science, and Black Box Activities (Bell, 2008)	NOS, A way of knowing
		Inquiry into Light and Shadows (adapted from http://cpuproject.sdsu.edu/default.html	Waves and inquiry
Day 4: Scientific Inquiry and Engineering	Mar.	Inquiry into Magnetism (adapted from http://cpuproject.sdsu.edu/default.html)	Energy, magnetism
		Inquiry and Engineering, *A Slick Solution: Cleaning an Oil Spill* (EiE Unit)	Engineering practices and ecosystems
		Force and Motion with Vernier Probes (6th grade middle school teachers only)	Force and changing motion
Day 5: Engineering, Modeling	May	Model – Eliciting Activities (MEA) (Moore, 2008) and Poster Showcase	Data analysis and engineering

Table 2

The Number of Teachers in Different Grade-Levels

Schools	Districts	Classroom Teachers				Specialists		
		6th	5th	4th	3rd	Science	STEM	Curriculum
Elementary 22 Public 3 charter	13	19	40	39	39	14	1	2
Upper elementary 18 Public	4	42				1		1

Table 3

Description of the Codes

Codes	Descriptions
Purpose	The engineering lesson should include clear learning goals and objectives
Context	The engineering lesson should be grounded in a realistic, meaningful, motivating context in which students apply engineering design process (e.g., an engineering problem that is framed in the context of fictitious engineering company)
Engineering Design	The engineering lesson should engage students in the engineering design which is an iterative process involving identifying an engineering problem, researching the problem, planning, designing a prototype, testing and evaluating the prototype, and re-designing
Science Connections	The engineering lesson should include meaningful instances of science

Table 4

Categories of the Engineering Lessons

Category	Description
Complete Engineering Lesson	The lesson includes all elements of an engineering design cycle and incorporates these elements through a realistic context. Also, the lesson has a clear purpose and science connections.
Design-Focused Engineering Lesson without a Realistic Context	The lesson follows an engineering design cycle, but is missing the use of a realistic context
Design-Focused Engineering Lesson without Re-design	The lesson follows an engineering design cycle, but is missing the re-design
Build and Test Only Lesson	The lesson does not follow an abbreviated engineering design cycle including only building and testing without needing to apply content information
Misapplication Lesson	The lesson is a science activity, but the teacher refers to it as an engineering design lesson.