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Hui-Hui Wang

Tamara J. Moore

Gillian H. Roehrig

See next page for additional authors

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STEM Integration: Teacher Perceptions and Practice

Hui-Hui Wang, Tamara J. Moore, Gillian H. Roehrig, and Mi Sun Park

University of Minnesota

Abstract

To gain a better understanding of teachers' beliefs about, perceptions of, and classroom practices using STEM integration, a multi-case case study was conducted with three middle school teachers. These teachers were purposefully selected from a pool of teachers involved in a year-long professional development module on STEM integration to represent science, mathematics and engineering teachers. This study addresses the following research questions: (1) What are teachers' beliefs about and perceptions of STEM integration after a year-long teacher professional development training? and (2) What is the connection between beliefs about and perceptions of STEM integration and teachers' classroom practices? Data collection consisted of document analysis, classroom observations, and interviews. Data were analyzed using the constant comparative method. Findings from the case studies suggest that (1) the problem solving process is a key component to integrate STEM disciplines, (2) teachers in different STEM disciplines have different perceptions about STEM integration and that leads to different classroom practices, (3) technology is the hardest discipline to integrate in these cases, and (4) teachers are aware of the need to add more content knowledge in their STEM integration.

Keywords: STEM integration, professional development, case study

Introduction

The report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (National Academies 2006) states that the United States is losing its competitive position within the science, technology, engineering and mathematics (STEM) fields because students are failing to keep up with other countries. Growing concern about developing America's future scientists, technologists, engineers, and mathematicians to remain viable and competitive in the global economy has re-energized attention to STEM education. To remain competitive in a growing global economy, it is imperative that we raise students' achievement in STEM subjects. The report recommends a comprehensive investment in quality STEM educational programs that will increase the quality and knowledge of the STEM field teaching force.

The problems that we face in our ever-changing, increasingly global society are multidisciplinary, and many require the integration of multiple STEM concepts to solve them. These complex problems are the driving force behind national calls for changes in STEM education (National Academies, 2006; National Center on Education and the Economy (NCEE), 2007). Although educators are aware of the importance of STEM education, neither educators nor researchers consistently agree or understand what STEM education should really be about in K-12 education. Currently, STEM disciplines are taught in silos. But the nature of the work of most STEM professionals blurs the lines between disciplines. Therefore, teaching STEM disciplines through integrating them would be more in line with the nature of STEM. As the nature of STEM is an integration of the four subjects, science, technology, engineering, and mathematics, many questions remain indistinct in K-12 STEM education. One of the biggest educational challenges for K-12 STEM education is that few general guidelines or models exist for teachers to follow regarding how to teach using STEM integration approaches in their classroom. Thus, research needs to be done to look at teachers' understandings and implementation of STEM integration.

Many states, such as Texas, Oregon, and Massachusetts, are legislating efforts to improve STEM education through the addition of engineering standards to the existing science standards (Kuenzi, Matthews & Mangan, 2006; National Governors Association 2007). In 2009, Minnesota added engineering concepts to the new academic standards for K-12 science education. The state documents demonstrate that the intent is for engineering being integrated into science classes, rather than to be taught as a separate subject. As the majority of science and mathematics teachers lack knowledge and experience of teaching engineering and STEM integration, the Minnesota Department of Education has funded several professional development programs for teachers to learn about STEM integration.

Research Questions

This study explores the impact of professional development related to STEM integration on teacher beliefs, perceptions, and practices. Attention was paid to teachers' understanding of STEM integration, implementation, practices, and perceptions of the most effective ways for their students to learn and engage with STEM concepts. The research questions that guide this study are as follows:

1) What are teachers' beliefs and perceptions of STEM integration after a year-long teacher professional development training?
2) What is the connection between beliefs about and perceptions of STEM integration and teachers' classroom practices?

Theoretical Framework

This paper builds upon the STEM integration research paradigm (Moore, 2010). Here, STEM integration is defined to be the merging of the disciplines of science, technology, engineering, and mathematics in order to: (1) deepen student understanding of each discipline by contextualizing concepts, (2) broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increase interest in STEM disciplines by increasing the pathways for students to enter the STEM fields (Moore, 2008). Our STEM integration research is guided by the following:

1) Rich and engaging learning experiences that foster deep content understanding in STEM disciplines and their intersections are needed for students. Therefore,
2) there is a need for curricula that integrate STEM contexts for teaching disciplinary content in meaningful ways that go beyond simply blending traditional types of understandings; and
3) new models of teaching must be developed if STEM integration is to lead to meaningful STEM learning, given that most teachers have not learned disciplinary content using STEM contexts, nor have they taught in this manner.

STEM integration is an interdisciplinary teaching approach, which removes the barriers between the four disciplines.

Background Literature

Curriculum Integration

STEM integration in the classroom is a type of curriculum integration. The concept of curriculum integration is complex and challenging, as integration of subjects is more than a matter of simply putting different subject areas together. The idea of curriculum integration is derived from educators' awareness that real world problems are not separated into isolate disciplines that are taught in schools (Beane, 1995; Czerniak et al., 1999; Jacobs, 1989). In many cases, people need skills that cut across the disciplines. Even with this in view, researchers and educators have not come to a consensus around a clear definition and conceptualization of curriculum integration (Czerniak et al., 1999; Huntley, 1998). Research studies are often not clear about the terminology that has been used to describe integration (Beane, 1995; Czerniak et al., 1999; Drake, 1998; Lederman & Niess, 1997).

Two words that have been used frequently in the literature to describe integration are "multidisciplinary" and "interdisciplinary." Most research studies attempt to distinguish these two by focusing on the paths and degree of integration. Lederman and Niess (1997) used the metaphor of chicken noodle soup versus tomato soup to explain the fundamental differences between multidisciplinary and interdisciplinary approaches to integration. In their description, multidisciplinary integration was characterized as a bowl of chicken noodle soup, where each ingredient maintained its identity without direct mixture, yet still came together to make a whole. On the other hand, tomato soup represented an interdisciplinary approach to integration, in which all ingredients/subjects were mixed together and could not easily be separated. In other words, they suggested that in the multidisciplinary approach, a learner could easily identify each subject. In contrast, an interdisciplinary approach was like a melting pot in that the boundaries among subjects were blurry. Overall, multidisciplinary begins and ends with the subject-based content and skills

(Beane, 1997; Bellack & Kliebard, 1971), and students were expected to connect the content and skills in different subjects that had been taught in different classrooms. As for interdisciplinary, the approach begins with a problem or an issue that centers the content and skills in multiple disciplinary subjects (Beane, 1997; Bellack & Kliebard, 1971). The concepts of interdisciplinary integration are interconnected beyond a theme, such that they cut across subject areas and focus on interdisciplinary content and skills, rather than subject-based content and skill (Drake, 1991; 1998; Jacobs, 1989).

Many researchers suggest that an interdisciplinary curriculum is the best form of curriculum integration. Interdisciplinary curricula start with real world problems or issues. The essential elements that need to be considered in an interdisciplinary curriculum include such skills and knowledge as critical thinking, problem-solving skills, and making connections with learning experiences that relate to personal meanings (Beane, 1991; 1997; Jacobs, 1989; Miller, 1995; Nielsen, 1989).

Meaningful Learning in Curriculum Integration

Many research studies have found that traditional didactic lecture may lead to memorization of factual information, but often fail to elicit comprehension of meaningful learning (Honam, 2002; Loverude, Kautz & Heron, 2002; Wright et al., 1998). Meaningful learning occurs when learners make connections between prior knowledge and new experiences and skills within real world contexts (Brooks & Brooks, 1993). Hirst (1974) pointed out that separated subject areas restricted learning by making learners alienated from real world experiences.

Advocators of curriculum integration suggest that curriculum integration attempts to give students more meaningful learning experiences by connecting disciplinary knowledge with personal and real world experiences (Beane, 1991; 1995; Burrows *et al*., 1989; Capraro & Slough, 2008; Childress, 1996; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). Beane (1997) pointed out that curriculum integration involved four major aspects: the integration of experience, the social integration, the integration of knowledge, and the integration as a curriculum design. The *integration of experience* suggests that learning involves integrating past experiences to make meaning of new experiences, or replace existing knowledge. *Social integration* is a necessary channel whereby learners can collaborate and share knowledge and experience to make learning more accessible and meaningful. The *integration of knowledge* emphasizes that knowledge is constructed by individuals through active thinking in approaching issues in their life. In other words, when solving a real problem in life, knowledge is not accessed as separate subjects. The *integration as a curriculum design* advises the organization of curriculum around problems and issues that are of personal and social significance in the real world. Simply put, curriculum integration provides a framework for integrating meaningful content in real life problem solving settings. Therefore, the focus of the integration approach demonstrates that curriculum integration was grounded in the tenets of constructivism. Curriculum integration provides learning experiences that connect learners' prior knowledge with real world contexts, as well as an environment where meaningful collaboration is needed.

STEM Integration

If we treat STEM integration as a type of curriculum integration, it manifests its expression; a curricular approach that integrates science, technology, engineering and mathematics. STEM integration offers students one of the best opportunities to experience learning in a real world situation, rather than to learn bits and pieces and then to have to assimilate them at a later time (Tsupros, Kohler & Hallinen, 2009). While there is a continuing need to clearly define a theoretical framework for STEM integration (Lederman & Niess, 1998), as well as understand curricular and classroom practices (Venville *et al*., 1999), the goals for an effective STEM instruction have been vigorously discussed.

By using engineering accreditation standards, Sanders (2009) argued that the focuses of STEM education should apply knowledge of mathematics, science and engineering, design and conduct experiments, analyze and interpret data, and communicate and corporate with multidisciplinary teams. The report *Improving Undergraduate Instruction in Science Technology, Engineering, and Mathematics* (National Research Council, 2003) that suggested an effective STEM education should not only focus on science content, but also foster "inquisitiveness, cognitive skills of evidence-based reasoning, and an understanding and appreciation of the process of scientific investigation" (p. 25). Additionally, Morrison (2006) provided the criteria for what an effective STEM instruction should look like in a classroom. She suggested in a STEM integration classroom students should be able to perform as 1) problem-solvers, 2) innovators, 3) inventors, 4) logical thinkers, and also be able to understand and develop the skills needed for 5) self-reliance and 6) technological literacy. An analysis of different STEM programs and curricula designs revealed that many researchers and educators agreed on the two major foci of STEM integration: (1) problem solving through developing solutions and (2) inquiry (e.g., Clark & Ernst, 2006; Felix & Harris, 2010; Morrison & Bartlett, 2009; Yasar et al., 2006). Therefore, teaching STEM integration not only needs to focus on content knowledge but also needs to include problem-solving skills and inquiry-based instruction.

With these views in mind, the purpose of this paper is to research teachers' beliefs and practices while implementing self-identified STEM integration activities developed through participation in a yearlong STEM integration professional development program.

Methods

A qualitative case study (Yin, 2003) was used to determine teachers' beliefs about and perceptions of STEM integration and the way in which these beliefs and perceptions are translated to classroom practice looking at three teachers from one middle school, who participated in a year-long professional development program on STEM integration.

STEM Integration Professional Development Program

The *Secondary STEM Integration* teacher-training module was a professional development program that provided STEM integration experiences for STEM teachers in grades 6–12. Primarily filled with mathematics and science teachers, the program sought to help science and mathematics teachers become familiar with the new Minnesota engineering standards and to encourage the incorporation 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 understandings 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 PLC activities were highly structured and closely tied to the training days of the module for teachers to meet together and reflect on how what they learned during the training sessions, and to share/learn how to implement the training into their classrooms. 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 (Lesh & Doerr, 2003), (4) integrating technology to enhance learning of science, engineering, and mathematics, and (5) orchestrating student discussions around STEM concepts (see Table 1 for more detailed information about each training day). The facilitators focused on providing direct STEM integration learning experiences that were used to develop a framework for STEM integration and sample activities that could be used by teachers in their classrooms.

The professional development program highlighted the nature of the disciplines of STEM as well as the integration of the disciplines. Particular attention was given to the nature of engineering as a design science and to the nature of technology. The training looked at engineering through the lens of design, taking the view that engineering practice, at its core, is a way of thinking in order to solve problems for a purpose. The engineering design process was presented in multiple forms but always highlighting the fact that it is the "distinguishing mark of the engineering profession" (Dym, 1999). According to ABET, the accrediting board for post-secondary engineering programs in the United States, engineering design is " a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs" (ABET, 2008, p. 2).

The training also focused on two common definitions of technology. In the more inclusive view, technology is defined as the process by which humans modify their

Table 1
Outline of the five training days for 6–12 STEM Integration Module

Time Allocated	Content to be delivered	Participant Processes
Day 1 October	**What is engineering and engineering design?**	Overview of the nature of engineering, introduction of the engineering design process. Teachers participated in a concept mapping about "what is engineering?" and an activity to develop their understanding of the engineering design cycle through wind turbine blade design. Teachers ended the day in a college-level "active classroom" and had two presentations of active learning by STEM professors from the University.
Day 2 December	**Math Science and Redesign**	What makes engineering different from mathematics and science. Teachers continued working through simulated student problems on engineering design – through wind turbines' gear ratios and generators; worked through a redesign activity with constraints based on their blade designs from Day 1.
Day 3 January	**Problem Solving and Modeling**	Teachers worked through the model-elicitation (Lesh & Doerr, 2003) process within the STEM disciplines.
Day 4 March	**Integration through Technology Tools**	Teachers learned a variety of ways to use technology in their classrooms as a means to integrating STEM.
Day 5 May	**Representation, Translation, and Celebration**	Teachers learned models of student understanding (representational fluency) through participation in a heat transfer based Engineering Teaching Kit (Schnittka, Bell, & Richards, 2010); National Speaker presented; Teachers participated in a poster session as a summary to their year of STEM Integration to MDE Deputy Commissioner.

surroundings to fit their needs and desires (International Technology Education Association (ITEA), 2000). In order to meet needs, engineering, mathematics, and science play an integral role in the modification. The second definition focuses on artifacts of technology: computers, medicine, wind turbines, etc. The National Academy of Engineering (2011) states that technology "includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts ... The knowledge and processes used to create and to operate technological artifacts – engineering know-how, manufacturing expertise, and various technical skills – are equally important part of technology." Real-world problems often employ technologies, and creation or modification of technologies is the solution to the problems.

Participants

Three teachers were purposefully selected from the STEM integration professional development program. All three participants were STEM middle school teachers in the same high-needs urban school (73% Free and Reduced Lunch, 25% English Language Learners, 66% Students of Color – 3% American Indian, 7% Asian, 32% Black, 24% Hispanic, 34% White). We chose these three teachers to be participants based on four criteria. First, they all attended the STEM integration professional development trainings and completed all of the PLC activities. Second, during the STEM integration professional development training, they worked in the same group during almost every activity, therefore participating in the same conversations. Third, they had shown high interests in integrating STEM activities in their classroom practice in their PLC documents (e.g., the engineering unit plan). Fourth, the subjects these three teachers taught represented different individual STEM disciplines, i.e., Nate was a mathematics teacher, Kathy was a science teacher, and Amy taught engineering (pseudonyms used).

Nate was a white male mathematics teacher who taught sixth grade. He held teaching certificates in the area of elementary, math (grades 5–8), and science (grades 5–8). He had a total of 6 years of teaching experience. He identified himself as a non-user in STEM integration. He cooperated with Kathy to implement his STEM integration lesson.

Kathy was a white female teaching sixth grade physical science. Before she taught physical science, she had been a mathematics teacher in a middle school. She held teaching certificates in the areas of elementary, math (grades 5–8) and science (grades 5–8). She had 7 years of teaching experience and considered herself as novice user in STEM integration. She cooperated with Nate to deliver her STEM integration unit.

Amy was a white female teaching 6^{th}, 7^{th}, and 8^{th} grade engineering. Before she taught engineering, she had been a science teacher for several years. She held teaching certificates in the areas of elementary and science (grades 5–8). She had a total of 10 years of teaching experience. In her engineering classes, Amy centers her instruction on different engineering projects, such as designing a lighthouse, prosthetics devices, and cardboard chairs. Each topic represents a larger unit (usually 1–2 months of class time) and is student-centered, inquiry-based instruction. She identified herself as an intermediate user in STEM integration. She worked with a mathematics teacher (not included in this study) when she taught her STEM unit. Table 2 provides an overview of the three participants.

STEM Integration Units

As part of the directives for both the STEM integration professional development training and PLC, the teachers were required to design a STEM integration lesson or unit and implement it in their classrooms. Below are brief descriptions of the unit or lesson of each teacher in this study.

Kathy and Nate collaborated to implement their STEM integration unit. This was a multidisciplinary approach to STEM integration. Their unit had the context of packaging engineering. Kathy designed the overall unit plan, with help from Nate where the mathematics was concerned. The length of her part of the lesson plan was 7 days. In this unit, she was responsible for teaching science and engineering concepts. Nate was responsible for designing and teaching mathematics concepts. He focused on geometric shapes. His part of the unit was one day long. The major foci for each STEM discipline in their lesson plan were: 1) problem solving (mathematics), 2) inquiry-based teaching (science), 3) geometric shapes (mathematics), 4) engineering design cycle (engineering), and 5) background information research by using computers (technology). Note: the teachers' idea of technology integration is a limited view of technology as compared to the definitions of technology highlighted in the teacher professional development.

Amy's STEM lesson plan was designing cardboard chairs. The unit was two months long. The engineering challenge for this lesson unit was to build an adult-sized cardboard chair that could hold 150–200 pounds. She told students that the chairs that were of high enough quality

Table 2
Teachers' demographic information

Teacher	Nate	Kathy	Amy
Subject	Mathematics	Physical Science	Engineering
Grade	6^{th}	6^{th}	6^{th} through 8^{th}
Teaching experience	6 years	7 years	10 years
STEM integration experience	Non-user	Novice	Intermediate
Licensure(s)	1. Elementary 2. Math 5–8 3. Science 5–8	1. Elementary 2. Math 5–8 3. Science 5–8	1. Elementary 2. Science 5–8

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would be placed up for auction and the proceeds would go to a local charity ("Chair-ity" was the name of her unit). The major foci for each STEM discipline in her lesson unit were: 1) problem solving (mathematics), 2) human body structure (science), 3) measurement and calculation (mathematics), 4) engineering design cycle and team work (engineering), and 5) background information research by using computers (technology). Again, this teacher had a limited view of technology integration, when, in fact, the student-created product was a technology.

More information about each unit will be provided in the cases. Table 3 shows an overview of the units for each participant.

Data Sources

In order to facilitate the triangulation process (Maxwell, 1996) for conducting this multi-case teacher case study, the data collected included: 1) document analysis of the STEM integration unit plans, 2) classroom observation(s) during the STEM integration unit implementation, and 3) a semi-structured interview about teachers' perceptions of and beliefs about STEM and STEM integration. The same researcher collected all forms of data.

Document analysis

The teachers in this study were required to turn in full unit plans for their STEM integration unit as a part of the teacher professional development PLCs. These plans were analyzed for the three teachers in this case study as a means to understand the entirety of their unit, to verify observation findings, and to look for evidence of teacher beliefs in their classroom practice.

Classroom observations.

The main focus for classroom observations was to observe teachers' classroom practices in using STEM integration. The teachers were required to complete a series of STEM lesson plans and activities as part of the professional development program. Therefore, the classroom observations were conducted during the participants' implementation of their STEM integration units. A classroom observation protocol and field notes were used to record classroom observation data. The classroom observation protocol provided an overview for the STEM lesson plan. The categories of the classroom observation protocol included coding for classroom description for each 5 minutes of instruction, type of lesson arrangement and activities, quality of the lesson, and Newmann's scoring criteria for authentic classroom instruction (Newmann & Associates, 1996; Newmann & Gamoran, 1996). On the other hand, the purpose for the field notes was to provide detailed descriptions for classroom practices in 5-minute increments throughout the class, including details such as the language that the teacher used to deliver her/his lesson plan and the interaction between the teacher and the students. Due to time restrictions and miscommunications, the researcher had observed Kathy's class once. Because of the length of Nate's STEM lesson plan, the researcher conducted one observation for his class. As for Amy, the researcher was able to conduct four classroom observations for her STEM lesson plan.

Teacher interviews.

One interview was conducted with each teacher after completing the STEM integration professional development program and the implementation of their STEM integration unit. The semi-structured interview was approximately 45 minutes long. The questions focused on teachers' perceptions of and beliefs about the individual STEM disciplines and the integration of these disciplines as a means for student learning. There were three parts to the interview. First, the teachers described the nature of each STEM discipline. Second, a series of questions addressed teachers' perceptions about the meaning of STEM integration and their classroom practices for STEM integration. In this part of interview, the questions focused on the difficulties with, benefits of, and ideas about STEM integration in their classroom. Finally, the teachers were asked about their beliefs about the impact of STEM integration on students. Interviews were transcribed verbatim to produce fruitful data (Becker, 1970).

Table 3
STEM lesson plan overview for each teacher

Teacher	Nate	Kathy	Amy
Context	Packaging Engineering	Packaging Engineering	Building a Cardboard Chair
Length	1 day	7 days	2 months
Goal for the lesson plan	Learning various geometric shapes	Designing a package to ship stained glass to Europe	Building an adult-sized cardboard chair that could hold 150–200 pounds
The focus of science	None	Inquiry-based teaching	Human body structure
The focus of mathematics	Perimeter, interior angle, exterior angle of a polygon, and tessellation	Problem solving	Measurement and calculation, such as ratio and average. Problem Solving.
The focus of engineering	None	Engineering design cycle	Engineering design cycle and team work
The focus of technology	None	Background research by using computers	Background research by using computers

Data Analysis

To fully understand the cases, both classroom observations and interview data were read carefully several times. The classroom observation and the interview data were thoroughly examined individually and a cross-comparison was completed in order to provide deep understanding of the issues. First, the constant comparative method (Strauss & Corbin, 1990) was utilized to identify the central themes and relevancies for STEM integration. Four criteria were used to apply the constant comparative method (Boeije, 2002) for each case: description (analysis activities), aim, important question (issue), and result. Assertions and categories were created by coding each unit of the data in the first two criteria. After identifying the assertions from the data, a number of categories emerged. These categories eventually formed the themes and results. These categories involved specific units of data and assertions being recoded across the cases. The following is an example of how the data were analyzed:

Data:

"*I think STEM integration is fairly natural. I taught math and science, so I get both sides of it. My father was a civil engineer. When I was young, I watched how my father did his work. So, it is natural for me to think about how to integrate science, math, and engineering. That is part of who I am.*"

Four Criteria from the Data:

1. Open coding of description (analysis activities): fairly natural, personal experience/background, STEM integration, and who I am.
2. Aim: personal experience/background vs STEM integration
3. Question (issue): personal experience/background may contribute to the difficulties/doubts of STEM integration.
4. Result: Because the interviewee has personal background/experience highly relevant to STEM subjects, STEM integration to this interviewee is 1) not a new idea, 2) fairly natural, and 3) not a struggle.

After identifying the open codes and results from each case, we used cross-comparison to dissect and array the evidence across the three cases to generalize teachers' perceptions about STEM integration (Yin, 2003). For example, an open code, *STEM subjects are related*, occurred for all three teachers. The following are excerpts from their interviews in which this code was present:

Nate: Science is a framework to approach problem solving by using scientific methods, and engineering brings them all together.

Kathy: When I think about math in science, I think about problem solving as part of math … and engineering is like inquiry with problem solving.

Amy: Science and math are the content knowledge that needed to be used to solve a problem in engineering.

Therefore, a generalization that came from this open coding activity was that all three teachers believed that STEM subjects are related in a natural way.

Results

Mathematics Teacher Case – Nate

Nate cooperated with Kathy to implement his STEM lesson unit on packaging engineering. His lesson unit length was one day lasting for 90 minutes. There were 25 students in the class. In the beginning of his class, he spent 10 minutes introducing the problem: a church in Europe broke their stained glass window and will buy their replacement stained glass from the U.S. He told students that they would be designing packages in Kathy's class to ship these stained glass windows to Europe, but they needed to learn how to measure different shapes of polygons before they can design their packages. This was used as a context to motivate the content learning. He said, "If you (students) don't know how to measure them (the polygons), you will not know how to design a package that can fit them. So, in my class, we are going to work on that (measuring polygons)." Therefore, in his class, he used STEM integration, particularly engineering integration, as the context to connect his mathematics teaching with other STEM disciplines. After that, he spent 15 minutes to show different stained glass windows and talked about different shapes of polygons. Then, he gave a handout to his students and he had demonstrated how to complete the handout step-by-step. The handout included different measurement categories, such as number of sides, length of side, perimeter, interior angle, exterior angle of a polygon, and tessellation. After the demonstration, he gave each student several different shapes of polygons, and asked students to complete their handout. He walked around the classroom and helped students who needed assistance. At the end of class, he asked students to share their answers and demonstrate how they measured their polygons.

His lesson did not engage students with investigation (or problem solving), and also did not provide an environment where either students could challenge ideas or could pose their questions. His class was very structured and teacher-led. He demonstrated what students needed to do, and students followed that step-by-step. Therefore, in his class, most of the questions were basic recall of facts. Although he encouraged students to explain how they solved the problem, students were using the same procedures as he demonstrated to them.

Assertions and Evidence – Nate

Nate considered mathematics to be an important skill that students need to have, and STEM integration provides *the opportunity for students to apply mathematics skills and concepts in a real-world situation.* He said "STEM is an opportunity for students to see how I use different mathematics concepts and skills that I have, and how can I use these concepts and skills in real-world problems."

Nate believed mathematics, science, and engineering are all related. He stated, "Science is a framework to approach problem solving by using scientific methods, and engineering brings them all together." His beliefs matched his classroom practices. In his STEM lesson, he indicated that mathematics is a very important tool to solve a real-world problem to students by saying "If you (students) don't know how to measure them (polygons), you will not know how to design a package that can fit them." However, he was not able to give a clear definition for technology. Nate referred to technology as using computers to do research and presentations. He said, "If it (technology) is used well, it is a resource for research and presentation."

To Nate, when a mathematics teacher wants to use STEM integration, he/she needs to collaborate with teachers in other STEM disciplines. In the interview, he mentioned several times how he wished to have a networking system with other teachers. He said, "If we (teachers) can align the classes somehow so we can do the related subjects at the same time to build in STEM challenges or engineering projects together, that would be really helpful," and, "For math teachers, it is helpful to collaborate with other teachers to do STEM." He emphasized the importance of collaboration among teachers (again a multidisciplinary view of STEM integration), because *he believed that STEM integration could only help parts of his teaching, if a STEM project does not address mathematics standards.* That was another reason he believed STEM integration could increase his students' interested in learning mathematics but did not help him to teach his subject in a more effective way. He said, "Although kids enjoy it (STEM integration), I still have my regular math curriculum that I am responsible for. I still have to meet all the standards. That is my job. Engineering (problem solving piece) can help me, but not really help me to cover my curriculum." Therefore, he also wished to have STEM projects/curriculum not only apply to mathematics standards, but also clearly indicate how each discipline in STEM is being addressed. He said, "I think if we can have 3 or 4 sets of projects, such as with 6^{th}, 7^{th} and 8^{th} grade, what you do in science, math and engineering, would be really nice." He thought the STEM professional development program helped him to see more connections among STEM disciplines in a way that he did not see it before.

Science Teacher Case – Kathy

Kathy's STEM integration unit was set in the context of package engineering (as described in Nate's Case), and the length of the unit was 7 days. The one classroom observation was conducted in her first lesson. It was a 90-minute class. There were 18 students in the class. In the first 20 minutes, she gave a brief introduction about packaging engineering, described what students needed to do for the day's class, and divided students into groups. Then, she used another 10 minutes to explain the handouts, which were questions that students needed to complete for the class and a rubric for the scoring. After that, she moved her class to a computer lab. In the computer lab, she spent 20 minutes providing some basic information about how students can use computers, such as how to do their research and how to save their documents. In the rest of her class, she let students work on their questions, and she walked around to help students who needed assistance.

Her class mildly engaged students in investigation (or problem solving). The class did not provide an environment where students either could challenge ideas or could pose their questions. For example, she mostly gave students directions and students followed. Even though she let students work on their own to do background research, she provided the questions that students needed to answer and also gave the scoring rubric to them. This indicated that she set up standards for students to complete their work. For example, she said, "Guys, the answers will not come out from the computer directly. You need to do some reading and combine the information with your own ideas, and that is what I want to see in the answers." Therefore, her students rarely (almost never) asked higher-level questions during the class. Based on the documentation of the whole unit, it is reasonable to assume that because of the emphasis of the design cycle and the hands on nature of this project, this observation was not representative Kathy's teaching style in all situations.

Assertions and Evidence – Kathy

Kathy believed problem solving is a key concept to integrate STEM subjects and also is the main focus of STEM integration. Because of problem solving, she believes her students learn her subject more effectively. When Kathy was asked to talk about the nature of each STEM subject, she said, "When I think about math in science, I think about problem solving as part of math, and (students) should be able to use those skills, not so much basic math skills, more like analytical skills [that] focus on problem solving," and "engineering is like inquiry with problem solving, like coming out of different solutions, leaving things open-ended, and creating something." During the interview, she stated, "problem solving is a big deal in STEM integration. It really is part of all subjects and topics." Therefore, she emphasized problem solving in her STEM lesson plan. Kathy gave some examples how she integrated STEM subjects in her teaching, she said "[I use] problem solving pieces. [Students] figure out things on their own - how to make things work. When they (the students) are able to discover it and see it and make it work on their own, they will remember that a lot more, instead of just read about it or just follow the lab [directions that] said to do this or that." Although Kathy's observed class showed that she set up the problem solving procedures and students followed, her overall STEM integration unit plan indicated that she enacted this belief in a student-centered manner.

Kathy considered technology integration the most difficult part of STEM integration. Like Nate, Kathy mostly referred to technology as computers and on-line tools. Due to her students' lacking abilities and limited school technology resources, technology was equal to computers and on-line tools in Kathy's STEM integration unit, although it was evident that she knew it was more than that. She stated, "I was surprised to see my students didn't know how to use computers properly to do on-line research. I wish to use more technology [in my classes]. We only have 3 computer labs and need to share labs with all the students in school. I would like to be able to use laptops, and use on-line [applications] a little bit more."

She thought the STEM professional development program reinforced her beliefs about STEM integration, particularly the problem solving piece. However, she also believed that if students have more background knowledge before they come to a STEM classroom, students might learn more in applying problem solving. Therefore, if it were possible, she would like to flip the curriculum a little bit, such as teaching more content knowledge before asking students to apply problem solving. She said, "It will be really cool if kids have more background knowledge to do problem solving, such as more science and mathematics content knowledge. They will catch it right away like, 'I know what I am doing.'"

Engineering Teacher Case – Amy

Amy's STEM unit, designing cardboard chairs, was two months long. Each one of her classes was 90 minutes. There were 18 8th grade students in this class. In her class, students needed to have a product; an adult-sized cardboard chair that could hold 150–200 pounds, by the end of the unit. On the first day of her class, she spent half of her class explaining what students needed to accomplish in this unit by giving students a monthly schedule. She also asked students to find their partners to work together on this project for two months. She asked students to decide their roles, such as a designer, a manager, or a builder in this project. She told students, "Your roles do not mean that you only responsible for that part of project. It means you have to collaborate with others in order to complete the project." She also brought her lesson into a real world situation. The chairs were built for a local charity (thus the name "Chair-ity" for her unit). Therefore, she told her students, "We are doing this for real. So, if your chair meets the standards, we will place your chair up for auction." After the introduction, she let her students use computers to do background research for their chairs in the rest of the class.

On the second day, she emphasized the importance of a human body structure for designing a chair and demonstrated how to measure each part of human body to students. In this lesson, she combined mathematics and science concepts together. The science concept was human body structures, such as bones in arms and legs. As for the mathematics concept, she asked students to measure each part of their partners' body, which were shown in the handout that she gave to them, after she demonstrated how to measure them. At the end of class, she asked students to think about the purpose for the activities in this day's class and ways in which they would use those data to design their chairs.

The third observation was conducted when students designed the blue print and set up the budget for their chairs. She first showed a video clip how to assemble cardboard joint. Then, she asked students how they could make joints stronger. Students provided an array of answers, and Amy tried all ideas to demonstrate if the ideas worked. She also had monetary constraints. One portion of the classroom was turned into a "store." Students had a limited amount of money they could spend at the store to build their chair. She asked students to think carefully about how to use their budget, so as to spend their money wisely. She said, "Controlling your budget is very important for engineering design. If you spend more money than your budget, you might lose your clients or company in the real world." For the rest of this class, she let students work on drawing the prototype of their chairs – emphasizing the need for iterative design. She emphasized that students should focus on the client (the one who would keep the chair) to find answers to their questions.

The last observation was conducted when students built their prototype of chairs. In this lesson, Amy embedded ratio as the mathematics concept. She reminded students that they needed to pay attention to the ratio between their prototype chairs and the real chairs that they wanted to design. Most of the time in this class, she let her students control the pace of building their prototype chairs, and she walked around to help students who needed assistance. Amy also emphasized the need for aesthetically pleasing chairs, and had students collaborating with an art teacher and art students for help when it was time for her engineering teams to paint their chairs. This created the need for her students to communicate with the art students in order to finish their project. Therefore, she said, "You need to pay attention to the deadline, because you will need to spend some time with the students from the art department. You need to schedule with them and discuss with them how to paint the chair in a way that you want."

Overall, her classes highly engaged students with problem solving and engineering design. In her classes, students were encouraged to challenge their ideas and also to ask their questions. Most of her classes were semi-structured, in which students needed to work on their own pace and could ask questions. Therefore, in her classes, students were encouraged to be independent, to do their own thinking, and to ask challenging questions.

Assertions and Evidence – Amy

To Amy, science and mathematics are content knowledge that helps her students to do problem solving in engineering. As for technology, she considered technology as the newest piece in her STEM teaching. She believed that in her school, they did not apply technology enough. She knew that technology is more than just computers. However, it was hard for her to use technology other than computers, because of the limited school resources. *Amy believed that in an effective STEM integration unit, the engineering piece needed to combine, not only problem solving, but also the content knowledge of science and mathematics.* She said, "I do think that the initial layer of engineering does need to be problem solving. But the next layer is that engineering really has to have content pieces. They (students) really have to understand when they should pull mathematics or science concepts in to help them solve the problem." *She believed STEM integration helped her students to think independently and to become more confident in learning, to learn how to communicate with each other, and to become skilled at teamwork.* She stated, "They (the students) start to think 'What am I good at? What am I weak at?' They start to ask us about different engineering jobs and [start to be] willing to take technology education classes in high school. STEM integration got them to think about their careers, futures, and [encouraged] the feeling that 'I can do it.' That was so cool!" Amy also stated, "I think communication and teamwork are other benefits that students learn from STEM integration. They have to learn how to work with others and how to handle controversies in a professional way." She gave an example - one of art student groups had broken one of her engineering team's chairs. She was amazed to see how her students put aside their anger in order to handle the situation in a very professional way (finding other solutions to rectify the situation).

Amy also believed that STEM integration could help other non-STEM disciplines as a means to help students understand the world. She stated, "STEM [integration] is one way to pull all the different disciplines together. In my 10 years teaching, I have never been able to figure out how to do that [until now]. I have a music teacher, an art teacher, and a social studies teacher all coming to me to say: 'Can we do something together?'" She thought the STEM professional development program enhanced her concept of STEM integration and provided more opportunities to expand her lessons. She said, "Now I can see so many possibilities and direction that I [my teaching] can go. The best thing about this is, kids love it." However, she still struggled with integrating content knowledge in her lesson unit in a way that makes the content explicit. *She felt she needed better ways to integrate content knowledge in her STEM unit.* She said, "Right now the difficulty that I am having is the content pieces. I really feel that kids understand the process of how to solve a problem. They are ready for more content in science and math. I need to figure out how to do that." Her classroom practice confirmed her beliefs. She constantly tried to find ways to add more science and mathematics content knowledge into her lesson plan. She discussed how to integrate more mathematics concepts into her unit with the collaborating mathematics teacher after each observed class.

Interpretation

All three teachers believed that science, mathematics, and engineering are related in a very natural way, either by content or problem solving processes. They all believe that problem solving plays an important role in integrating engineering into science and mathematics. However, they also think prior knowledge, such as science and mathematics content knowledge, is important for students to understand in order to be successful in STEM integration. Especially in mathematics, Nate suggests that problem solving does not help him to address the mathematics standards for which he is responsible. He needs more than just problem solving in STEM integration. Although the three teachers are able to see the connections among science, mathematics, and engineering, they all had a hard time talking about technology and how to integrate technology in their classroom practices. In both Amy and Kathy's classes, they connect technology in their STEM unit by using computers to do on-line background research. Both Amy and Kathy believed that their students need more opportunities to engage with technology. However, they both felt that their school is lacking technology resources. To Amy, "more opportunities to engage students with technology" means bringing in technology other than computers to teach her students. However, Kathy will be satisfied if her students can have more access to computers. These findings indicate that all three teachers came out of the STEM integration teacher training with limited views on the nature of technology.

Teachers' Beliefs and Perceptions of STEM Integration and Classroom Practices

In these three teachers' cases, their perceptions of STEM integration strongly influenced how they designed their STEM integration unit. These included perceptions about the foci of STEM integration, perceptions regarding the processes of how to teach a STEM integration unit, and beliefs about how STEM integration can improve their students' learning. It is interesting to note that the three teachers, who teach different subjects, have differing perceptions about STEM integration, and this led to different emphases in their STEM lesson units. For example, Kathy thinks problem solving is a main piece in STEM integration. Therefore, her STEM lesson unit is built around problem solving processes. Nate thinks one of the major benefits to integrate STEM in mathematics is real world context. Therefore, he teaches his unit by asking students to solve a problem that is set up in a real world context. Nate is the only teacher who is concerned that STEM integration does not help him address content standards. He felt in STEM integration, mathematics is a tool that can help to solve a STEM problem. Therefore, it was hard for him to apply STEM integration without cooperating with teachers in other STEM disciplines. This means his view and practice are highly aligned with the multidisciplinary view of STEM integration (Beane, 1997; Bellack & Kliebard, 1971; Lederman & Niess, 1997). Consequently, he helps Kathy by teaching the explicit mathematics concepts for her unit. As for Amy, the engineering teacher, she believes that her students benefit from STEM integration through many aspects, such as thinking more independently and working as a team. Therefore, her unit design and classroom practices provide students an environment that simulates a real engineering design project. The beliefs and practices of both Amy and Kathy demonstrate that they have an interdisciplinary view of STEM integration (Drake, 1991, 1998; Jacobs, 1989; Lederman & Niess, 1997).

The three teachers had different difficulties when they used STEM integration. Lacking digital technology resources (computers and other digital technology devices) and good STEM curriculum were two biggest barriers for all three teachers. Besides limited technology resources in their school, Amy and Nate talk about the need for STEM integration curricula that are divided by grade and subject. They think curricula and curricular alignment would be really helpful for them to see a whole picture how their subjects line up with other STEM disciplines and how they can integrate other STEM disciplines within their subjects.

All three teachers gave very positive feedback about how STEM integration boosts students' confidence level in learning science and mathematics. They all believe that STEM integration helps their students to not be afraid to make mistakes and to think that they are able to accomplish something that they could not do before. Additionally, they believe STEM integration increases students' interest in learning more about STEM disciplines, because their students have fun when they apply STEM integration in their classroom. Consequently, as Amy suggests, students show more interest in STEM disciplines as well as give more consideration to entering STEM fields as their future careers.

Teachers' Beliefs about STEM Integration Professional Development

The STEM professional development program confirmed and enhanced the teachers' thoughts about STEM integration. They believed the STEM professional development program provided more opportunities and connections on how to use STEM integration to teach their subjects. While the professional development program highlighted ideas of interdisciplinary STEM integration, a few models of multidisciplinary integration were presented as well. The findings suggest that teachers will begin doing STEM integration in the manner which is most comfortable to them and that this decision is highly correlated to their beliefs about the value and purpose of STEM integration.

Closing Remarks and Future Directions

STEM integration is an innovative way of thinking about teaching mathematics and science in K-12 that has the potential to impact education in a positive way. This case study has provided initial evidence that STEM integration can be implemented successfully and that teachers believe that this manner of teaching encourages student learning and student confidence in mathematics and science courses. The teachers in this study felt that STEM integration is a natural way to think about teaching since most real world problems cross disciplinary boundaries. Each of the three teachers took STEM integration to be something different. Nate and Kathy worked together to provide their students an overall STEM integration experience in a multidisciplinary model. Kathy's class contained integration of science concepts with engineering design elements, whereas Nate's class was set up as a mathematics lesson with an engineering context in order to inform the engineering design in Kathy's class. Amy took on an interdisciplinary model for her unit. The objectives for her unit included concepts from science, mathematics, and engineering design. The findings of this paper support the idea that some level of professional development is needed if STEM integration is to be sustainable.

This study provided a snapshot of one school and three teachers. Further study on this large-scale teacher professional development program (N = 78 teachers) on STEM integration is being conducted. A future research article will focus on teacher learning and teacher curriculum development through this program.

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