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Original Paper

Professional Development for Science Teachers on Integrating STEM: A Case Study

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Abstract

In the United States, the Next Generation Science Standards (NGSS) bring both commitment and challenges to science education in K-12 schools. New focus areas within the NGSS are engineering education and the integration of multiple disciplines as seen in science, technology, engineering and mathematics (STEM). Providing professional development (PD) is necessary in order to assist K-12 teachers with the implementation of the NGSS in their classrooms (NGSS Lead States, 2013). This case study shares the results of a unique style of PD workshops provided for K-12 teachers on the NGSS and engineering design where participants were immersed in inquiry-based STEM activities with an earth and space science theme. Twenty-six teachers agreed to participate in the study. This qualitative research focused on self-reported data through surveys, interviews, focus groups, and observation of participants during the workshops. Findings from this case study revealed self-reported increases in teachers' dispositions and self-efficacy regarding their implementation of the NGSS in an integrated STEM teaching context.

Keywords

STEM Teaching, Professional Development, NGSS Implementation, Inquiry Science Teaching, Engineering Education, Engineering Design, Early STEM Exposure

1. Introduction

It has been noted in the research that professional development (PD) for K-12 teachers in the area of science, technology, engineering, and mathematics (STEM) is critical as demonstrated through a direct link between teacher effectiveness and student learning (Nadelson, Seifert, Moll, & Coats, 2012). The amount of STEM-related content and pedagogy in teacher certification programs is limited, particularly for elementary teachers (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013; Fulp, 2002). There is a need to improve K-12 teacher preparedness to teach STEM at all levels, as well as impact their effectiveness (Bybee, 2010). Thus, PD is necessary in order to increase teachers' STEM content knowledge and their self-efficacy related to STEM teaching in order to improve their teaching effectiveness in science education. Aslam, Adefila and Bagiya (2018) emphasized the importance of teachers' direct involvement with STEM learning and outreach opportunities as co-learners in order to increase content knowledge, efficacy, motivation and enthusiasm. These characteristics are necessary in order to be effective with students and achieve the goal of inspiring them to pursue STEM careers. To this end, developing quality PD workshops that engages teachers in a common inquiry experience around research-supported practices is most effective (Richmond, Dershimer, Ferreira, Maylone, Kubitskey, & Meriweather, 2017). Such quality PD involves hands-on, active learning, and the modeling of inquiry practices. This type of PD workshop has been known to increase teachers' knowledge, skills, and self-efficacy related to STEM teaching (Beaudoin, Johnston, Jones, & Waggett, 2013). These principles directly impacted the creation of the STEM PD offered to urban K-12 teachers regarding the Next Generation Science Standards (NGSS) and engineering education presented in this case study.

A new piece to the science standards puzzle represented in the NGSS is the introduction of engineering design for students in kindergarten through high school (K-12). The vast majority of teachers, even at the high school level, are unprepared to effectively implement these new science and engineering concepts (National Academy of Engineering and National Research Council, 2009; Achieve, 2019). In addition, many elementary teachers, most of whom never majored in the science disciplines, are not adequately prepared in multiple STEM areas in order to feel confident enough to plan and implement NGSS-based lessons for their students (Goffin & Clegg, 2014). The introduction of these new standards requires that the teachers learn and understand scientific and engineering concepts. Thus, it is critical that K-12 teachers are engaged in the PD needed in order to be able to fully implement the NGSS-based teaching in the way envisioned by its writers (Center on Standards & Assessment Implementation, n.d.). The NGSS writers and others have acknowledged from the beginning that extensive PD would be necessary for K-12 teachers in order for full implementation of the new standards to be achieved (Center on Standards & Assessment Implementation, n.d.; Achieve, 2019). Yang, Xiufeng and Gardella (2018) agree and state that science teachers face a variety of challenges in implementing the new standards and PD is needed in order to assist teachers in meeting these new goals for science education in the United States.

This qualitative case study research was funded by the *NASA Connecticut Space Grant Consortium* and focused on studying the impact of providing inquiry-based PD for K-12 teachers on the different aspects of NGSS-based STEM teaching with an emphasis on earth and space science concepts. STEM teaching for the basis of this study is defined by the researchers as integrated content instruction within and across the disciplines of science, technology, engineering and mathematics. The researchers had aims of helping K-12 teachers acquire a greater understanding of how to successfully navigate and implement the new science standards with engineering principles through engagement in hands-on workshops where teachers experienced model STEM lessons that could be tailored to their specific grade levels. To that end, the goal of the study was to explore teachers' self-efficacy towards the incorporation of NGSS in STEM teaching after their engagement in the PD.

2. Literature Review and Theoretical Perspectives

2.1 Importance of NGSS

Through involvement with the new standards, students engage in scientific and engineering practices (SEP) targeted to build, deepen and apply their knowledge of science concepts and core related skills (NGSS Lead States, 2013). The NGSS incorporate engineering processes through an engineering design challenge approach which includes three core principles that engineers use: *Defining and delimiting problems, designing solutions, and optimizing the design solution* (NGSS Lead States, 2013). The framework emphasizes science and engineering practices to begin in the very earliest grades (kindergarten) and progress through elementary, middle and high school, engaging students in complex levels of STEM performance (National Research Council, 2012). Through the inclusion of engineering education for K-12 students, the National Academy of Engineering and National Research Council (2009) predicts an increase for K-12 students in the following areas: learning and achievement in math and science, understanding of engineering as a discipline, technology literacy, and the pursuit of STEM careers. In a study conducted by Wang and Nam (2015), the teacher participants acknowledged that integrating engineering principles with math and science provided an engaging learning environment that was highly motivational for students. These research-based science standards provide direction for educators to develop learning experiences for K-12 students that will stimulate their interest in STEM as well as prepare them with the content and skills needed for successful citizenry and college readiness. Students in grades K-12 need to be engaged in inquiry science that initiates authentic problems to solve, which in turn develops their critical thinking, conceptual and procedural knowledge (Duschl & Bybee, 2014, DeJarnette, 2012). This type of STEM instruction is what the writers and developers of the NGSS envisioned.

2.2 The "E" in STEM and Early Exposure

Recent attention has been brought to light in the United States regarding the low percentage of students pursuing STEM disciplines and degree programs (National Science Board, 2010). Recent data (National Science Board, 2016) show that in 2011-2012, approximately 23% of U.S. undergraduates were enrolled in STEM fields. The National Science Board (2016) also reports that about 18% of first-year students declared a STEM major upon entering college.

Research has shown that early exposure to STEM initiatives has a positive impact on elementary students' perceptions and dispositions (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Bybee, & Fuchs, 2006). Research also indicates that by exposing children to STEM disciplines during the K-12 years through hands-on, interactive, and problem solving activities, students' interest in STEM fields increases, which establishes an educational pathway for the future (Katehi, Pearson, & Feder, 2009; DeJarnette, 2018a).

Thornburg (2009) writes that engineering is the glue that holds the integrated STEM disciplines together. Oftentimes, in our society today, there is an attempt to increase the focus of STEM in education, but that focus tends to end up "siloing" science and math as separate entities, teaching them individually rather than integrated. Engineering education provides an optimal space to truly make STEM interdisciplinary. Engineering design challenges require students' interaction with science, technology, and math.

Many teachers have difficulty implementing engineering education into their existing science curricula (Wang & Nam, 2015). Since they have limited exposure or training in engineering education, they are not sure where to even start, especially at the elementary level. The NGSS presents engineering education as focusing more on the practices and processes of engineers, more so than content. However, the implementation of engineering practices along with the teaching of science and mathematics, is what ensures the integration of these fields into STEM. The process of an engineering design challenge is similar at the kindergarten level as it is at the high school level. The engineering design process of *Ask, Imagine, Plan, Create, and Improve* sets the stage for an engineering design challenge that is aligned to the NGSS where students identify a problem, craft a solution to the problem, and then test and improve their designs (Jackson, Heil, Chadde, & Hutzler, 2011). This simplistic process is used across grade levels K-12. What makes an engineering design challenge unique is working within certain identified limitations and constraints, such as materials and budget, which is where technology and math are emphasized within the process. Thornburg (2009) writes, "through engineering projects, students not only learn math, science, and technology, but understand the application of these fields in the realm of invention and problems solving" (p. 6).

A true STEM education needs to provide students with exposure and instruction of how things work and improve their use of technologies (Bybee, 2013). Engineering education lends itself to critical thinking and problem solving within certain constraints. In order to compete in our global economy, K-12 students must learn to problem solve, collaborate, adapt, think systematically, and use technologies. When American students graduate from high school, they should all equally graduate with a "STEM literacy" sufficient to ensure their success as citizens, regardless whether they choose to pursue a STEM field or not (National Academy of Engineering and National Research Council. 2009).

2.3 Professional Development (PD)

Professional development is essential in order to overcome teachers' limitations associated with minimal preparation and exposure to STEM, as well as the NGSS. Continuing education can help to fill in the gaps regarding teaching strategies and identifying valuable resources for teachers. Nadelson, Callahan, Pyke, Hay, Dance and Pfiester (2013) provided evidence in their study that demonstrated how even relatively short PD sessions can positively influence teacher confidence and efficacy when it comes to STEM teaching. Effective PD contains models of STEM teaching that are inquiry-based

(Capps & Crawford, 2013; DeJarnette, 2018b). Scientific inquiry is an effective approach to learning STEM concepts as students are engaged in authentic hands-on learning activities (Nadelson, Seifert, Moll, & Coats, 2012).

Engineering education is a new piece of the NGSS framework that requires teachers to implement engineering concepts and practices (SEP) into the curricula in all grades, from early elementary through high school (NRC, 2012). The term *engineering education* can be intimidating to many teachers who feel unprepared to teach the newest STEM concepts represented in the NGSS standards (Goffin & Clegg, 2014; Duncan, Diefes-Dux, & Gentry, 2011). Wang and Nam (2015) found in their study regarding the effect of providing PD on integrating engineering into teaching that teachers' unpreparedness to teach engineering education often negatively impacts their self-efficacy towards STEM teaching, which in turn can negatively influence their students. Nugent, Kunz, Rilett and Jones (2010) report that through PD, teachers' self-efficacy towards STEM teaching positively increased. Providing quality PD for K-12 teachers can therefore serve as a catalyst for improving student learning and achievement in the areas of STEM and engineering education (Thornburg, 2009; DeJarnette, 2012). This study aimed to build on this theoretical stance.

Professional development for teachers provides both instruction and exposure to how engineering processes are enacted at each grade level for K-12 students, and can therefore support their transfer into the science classroom. Implementing an engineering design challenge lesson supports a STEM interdisciplinary approach to teaching that is highly engaging, collaborative, and interactive for students (Thornburg, 2009; DeJarnette, 2012). This study aimed to provide teacher participants with PD that truly integrated STEM concepts in addition to highlighting engineering design to build their self-efficacy in STEM teaching.

2.4 Self-Efficacy of Teachers

Teacher efficacy has been identified as a major variable that contributes to teacher and student success in the classroom (Settlage, Southerland, Smith, & Ceglie, 2009). According to Tschannen-Moran, Hoy and Hoy (1998), this teacher efficacy is an important concept for those who design teacher PD, as it appears to have important effects on student achievement, attitude, and affective growth.

Myers (2014) identifies *self-efficacy* as one's impression of one's own proficiency on a task. This relates to how confident one feels in his or her performance or competency related to a specific task. Perceived self-efficacy can be defined as personal judgment of one's capabilities to organize and execute courses of action to attain designated goals (Bandura, 1977, 1997). Level of perceived efficacy is measured through examining the amount of one's certainty about performing a given task. Self-efficacy is influenced by personal experience, vicarious experience (modeling), and social persuasion over time (Bandura, 1977, 1997). Tschannen-Moran, Hoy and Hoy (1998) conducted a review of the theoretical and empirical underpinnings of teacher efficacy and concluded that it is the "teacher's belief in his or her capability to organize and execute courses of action required to successfully accomplish a specific teaching task in a particular context" (p. 215). Teachers' self-efficacy is therefore an intimate judgment of personal teaching competence, which includes an assessment of internal resources and constraints, and personal beliefs about the task requirements in a particular teaching situation, which include an assessment of resources and constraints external to the teacher (Tschannen-Moran, Hoy, & Hoy, 1998). As such, teachers' experiences in the classroom shape their self-efficacy in both positive and negative ways. When they feel well prepared and confident in their teaching abilities, they tend to demonstrate a higher self-efficacy. When teachers feel inadequate relating to their teaching abilities, or have had negative teaching or learning experiences, they often associate with lower levels of self-efficacy and dispositions.

Moreover, teacher self-efficacy has been described as context- and subject-matter specific. In particular, the effects of self-efficacy levels on the teaching of science have been studied extensively since the early 1990s and scholars have concluded that two unrelated factors play important roles in the teaching of science: personal science teaching efficacy (PSTE) and the science teaching outcome expectancy (STOE) (Gibson & Dembo, 1984; Riggs & Jesunathadas, 1993; Riggs et al., 1994; Watters & Ginns, 1995; Riggs, 1995; Enochs et al., 1995). Very importantly, previous research identified that as a result of their lack of training in STEM disciplines, teachers are often intimidated and lack self-efficacy regarding STEM teaching (Goffin & Clegg, 2014; Nugent, Kunz, & Jones, 2010). Teacher efficacy has been identified as a major variable that contributes to teacher and student success in the classroom (Settlage, Southerland, Smith, & Ceglie, 2009). In summary, teacher efficacy is an important concept for those who design teacher PD, as it appears to have important effects on student achievement, attitude, and affective growth (Tschannen-Moran, Hoy, & Hoy, 1998).

Teachers self-efficacy related to STEM teaching, in particular of engineering principles and processes, affect their pedagogical approaches to teaching engineering, thus the importance of this type of PD for teachers (Wang & Nam, 2015). Wang and Nam (2015) revealed that teachers' understanding of engineering and implementation strategies was more concrete with a heightened sense of self-efficacy after engagement in PD. This phenomenon heightens the importance of the role teachers play as change agents and the impact that their efficacy towards teaching principles of engineering education has on K-12 students' STEM learning (Tran, Nathan, Prevost, Phelps, & Atwood, 2011). Studies show that teachers' efficacy towards STEM teaching can increase with quality PD (Goffin & Clegg, 2014; Nugent et al., 2010). In this light, the urgent need for quality K-12 PD concerning integrated STEM teaching is of national importance.

2.5 Technological, Pedagogical, and Content Knowledge (TPACK)

Content knowledge (CK) refers to a teacher's knowledge about the subject matter to be learned or taught. The cost of not having comprehensive base of content knowledge can be prohibitive because students can receive incorrect information and develop misconceptions about the content area (National Research Council, 2000; Pfundt & Duit, 2000). Shulman's concept of pedagogical content knowledge (PCK) goes beyond knowledge of subject per se to the dimension of subject matter knowledge for teaching (Shulman, 1986). That is, he described the combination of knowledge of pedagogy and content as PCK. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult. Technological PCK integrates technology (TPCK or TPACK) and recognizes the importance of technology in education (Koehler & Mishra, 2009). TPACK therefore combines three knowledge components: technological knowledge, pedagogical knowledge, and content knowledge. TPACK, according to Schmidt et al. (2009), is a beneficial concept for thinking about the integration of technology into teaching and how teachers might then develop this knowledge. In addition, TPACK is the basis of effective teaching with technology, requiring an understanding of the representation of concepts using technologies, pedagogy, and knowledge.

STEM concepts should also be integrated into the PCK to increase the knowledge of teachers and educators in STEM teaching. Allen et al. (2016) stated that a robust STEM PCK ensures that teachers have the necessary knowledge to teach concepts related to STEM. This concept of STEM PCK has a purpose of focusing on developing student thinking as well as useful strategies for teaching related to STEM topics (Saxon et al., 2014). Experts believe in the importance of teachers having understanding about the pedagogical knowledge as well as subject-matter knowledge and updating them. Allen, Webb and Matthews (2016) state that a robust STEM PCK ensures that teachers have the necessary knowledge to identify and measure their student' development of concepts related to STEM. According to Shulman (1986), PCK represents the knowledge required to make subject matter knowledge (SMK) accessible to students, and SMK refers to the teacher's quantity, quality, organization of information, and conceptualization in their teaching area. These two types of teacher knowledge are key components of teacher competences that affect student progress (Diamond et al., 2014). Summarily, viewing any of these components in isolation from the others represents a real disservice to good teaching. The TPACK framework suggests that content, pedagogy, technology, and teaching/learning contexts have roles to play individually and all together (Schmidt et al., 2009).

2.6 Theoretical Perspective

The framework for this study was based on the sociocultural theory and the constructivist approach to learning by Vygotsky (1978), as well as the social learning theory presented by Albert Bandura (1971). Constructivist theory focuses on providing learning experiences through authentic problems that reflect their environment, which allows for taking ownership of the task at hand (Wilson, 1996). A key component of Vygotsky's sociocultural theory involves the learner gaining understanding through interaction with others and their environment. Through social interaction and reflection, we are able to develop cognition. Problem-based learning embodies principles of constructivism through engagement in experiences that present the learner with a problem to be solved, thus engaging students in critical thinking processes. The PD provided for the K-12 teachers embodied this same theoretical perspective where teachers were engaged in active learning and inquiry-based modeled STEM lessons (Beaudoin et al., 2013; Nadelson et al., 2013).

Albert Bandura's work is related to Vygotsky's theory, which emphasizes the central role of social learning. Bandura's social learning theory (1971) suggests that we develop understanding through interaction with and observation of the environment. By working collaboratively with peers to solve a presented problem, people learn from one another through active engagement. Our intellectual knowledge is supported and gained through collaboration, modeling, discourse and natural scaffolding processes (Vygotsky, 1978). Social learning theory spans both cognitive and behavior frameworks, by explaining human behavior in terms of continuous reciprocal interaction among humans, through the interaction of cognition, behavior, and environment. Bandura's social learning theory emphasizes the importance of observing and modelling behaviors, attitudes, and emotional reactions of others. The theory claims that human behavior can be learned by observing others, through modelling. This is called observational learning (Bandura, 2002). Bandura outlined key elements for such learning to occur: 1) Attention, or observational learning of modelled events, 2) Retention, or memory, including cognitive organization, 3) Motor reproduction of observed behaviors, and 4) Motivation, including external and internal. Because it encompasses attention, memory and motivation, social learning is very powerful. If learners experience positive consequences from a particular type of behavior, they are more likely to repeat that behavior and be confident that they are doing it well. Through this theoretical lens, this concept is defined as self-efficacy related to a particular behavior.

The PD activities included in this study reflect Bandura's theory as K-12 science teachers were provided the opportunity to observe effective STEM teaching paralleled by the opportunity to actively participate in the STEM processes. This approach, where study participants were "co-learners" promoted a collaborative learning community that embody the principles of active inquiry (Aslam et al., 2018). The PD engaged K-12 teachers in hands-on experiences that modeled the TPACK framework and STEM processes aligned to the NGSS with the goal that they would confidently implement similar activities within their own classrooms in the future. The STEM activities included in the PD for teachers relied heavily on a constructivist and sociocultural approach to learning for the teachers and for future use with their K-12 students. This was the theoretical framework used for the design of our PD workshops.

The intent of this study was to explore the phenomenon of the impact of an immersive hands-on approach to PD on teachers' self-efficacy in relation to NGSS-based integrated STEM teaching with the following research question:

R_1: *What is the self-efficacy related to NGSS-based STEM teaching and content knowledge for teachers immersed in a hands-on inquiry-based professional development*?

3. Methodology

This study is representative of a case study. A case study attempts to provide a holistic picture of a particular group using data collection methods such as observation, focus groups and interviews in order to draw conclusions (Frankel, Wallen, & Hyun, 2019). The researchers served as participant observers, whom DeWalt and DeWalt (2011) define as researchers who are directly involved with the daily activities, rituals, and routines of the group. The researchers in this case study facilitated the PD workshops for the teachers and participated in all workshop activities throughout the data collection process.

The NGSS science standards were introduced and adopted by the featured state in the United States in November of 2015 with implementation beginning in fall of 2016. It was necessary for teachers to receive assistance in order to understand the structure and implementation of these new standards. The researchers were awarded a grant from the *NASA Connecticut Space Grant Consortium* to provide PD for urban K-12 science teachers. Notifications went out to both public and private school teachers in two large urban areas of a northeastern state. In collaboration with the local Discovery Museum and Planetarium, the researchers provided teacher PD on navigating and implementation of the NGSS, engineering design instruction, technological and interdisciplinary STEM teaching strategies across all grade levels through immersion in a hands-on inquiry-based method. The PD had an earth and space science focus to match the interests of the grant initiative and a noted discipline represented within the NGSS. Three full days of inquiry-based workshops were offered for teachers in August, 2016. The project consisted of two identical workshops offered in two different major cities within the same state located in the northeastern United States. The workshop content focused on the development of teachers' knowledge of TPACK, integrated STEM teaching, and the structure and components of the NGSS framework through inquiry-based model lessons. The workshop format was represented by hands-on exploration along with content presentation which provided models of STEM learning activities and resources that teachers would be able to use with their K-12 students. The goal was to improve teacher participants' self-efficacy related to integrated STEM teaching and content through providing effective PD and mastery experiences for them to experience vicariously.

3.1 Participants & Setting

The setting of the research was located in the two largest cities in a northeastern state of the United States. The PD was offered on three consecutive days each summer for two summers. The invited participants were both public and private K-12 school teachers from the urban school districts represented within each city. Participants self-selected themselves to receive the PD.

Of the science teacher participants represented, 75% came from private schools within the local arch dioceses, and 25% came from public schools. Forty-nine teachers received the training, with 26 consenting to participate in the study. Thirty-five percent of the teachers were male and 65% of the teachers were female. The number of years of teaching experience represented was: 0-3 years, 19%; 4-6 years, 27%; 7-10 years, 15%, and 10+ years, 39%. An Institutional Review Board (IRB) application was submitted and approved at the university with which the researchers are affiliated. Informed consent was obtained from 26 participants from the 49 who were involved in the PD.

3.2 The STEM Workshops

The PD workshops were presented to K-12 teachers in an engaging hands-on format while providing suggestions for how to implement within their various grade levels. The majority of the lessons targeted grades 4-8, with instruction on simplifying or adding more challenge in order to meet extended grade level expectations. The PD workshops were conducted in two different urban locations over three consecutive days. The first session provided an in-depth introduction to navigating and implementing the NGSS, with time allowed for teacher exploration at their specific grade levels. The second session provided a hands-on model lesson using *Arduino* kits. Each teacher received their own *Arduino* kit paid for by the grant. Participants learned how to wire and program their beadboard to create a light-up dust sensor in addition to instructional strategies for implementing this lesson with their students.

The third session modeled a complete hands-on engineering design challenge where participants created a drag system (parachute) to land a payload (spacecraft) on Mars. Constraints were given and discussed, including materials, budget, and factors related to the Martian atmosphere. Participants worked in teams of two to plan, design, build, test and improve their parachutes following the engineering design loop. Participants tested their parachutes by dropping them off a second story stairwell and a discussion followed which focused on the differences between parachutes landing on Earth verses Mars. Math was emphasized through maintaining a budget, tracking drop times and distances, and calculating the surface area of their parachutes. Again, suggestions were made for simplifying the design challenge for younger students or making it more complex for older students.

The forth session introduced the teachers to crafting their own design challenges to meet the needs of their individual classrooms and curricula. Teachers received instruction on how to write an engineering design challenge that included constraints to replicate the work of engineers. For example, having students build mini rockets in connection with the NGSS crosscutting concept of the interdependence of science, engineering and technology. Participants also received ideas for resources, both digital and tangible. The fifth session provided specific mathematics-based STEM lessons on logarithmic functions and their application to biology, specifically drug dose response curves. This last session was geared towards high school educators.

On the third day of the PD, teachers participated in learning labs at the Discovery Museum and Planetarium. The museum has a simulated NASA Mission Control lab connected to a simulated spacecraft. Participants had the opportunity to experience how scientists and astronauts communicate electronically during spaceflight missions. Their simulated mission took them to Mars! The participants experienced what it was like to communicate via computers between Mission Control and the spacecraft while completing various scientific tasks and challenges. This is an activity the museum offers to schools for student field trips. Teachers also saw a planetarium show and ended the final day with an introduction to *Science on a Sphere® (SOS).* The museum has a huge glass sphere representing a globe that uses computers and projectors to display planetary data. Researchers at the National Oceanic and Atmospheric Administration (NOAA) developed the SOS as an educational tool to help illustrate Earth and Space system science (NOAA, n.d.). Using the SOS, images of atmospheric storms, climate change, temperature change, environmental processes and other complex data sets can be displayed that are very intuitive and captivating. Additionally, teachers received instruction on how to use this digital software within their own classrooms using a free download to their computer or

SMART boards to provide 2-D images.

3.3 Data Collection

A qualitative case study research design was chosen to investigate contemporary phenomenon within a multi-day inquiry-based professional development for K-12 science teachers. The qualitative data collection consisted of anonymous pre and post descriptive surveys, two focus groups involving six participants, four random teacher interviews, and field observations (conducted by the researchers) during the workshop sessions. The survey also gathered information from the participants such as gender, number of years of teaching experience, type of school, and grade levels taught.

The descriptive survey, interview and focus group protocol questions were similar in nature and piloted with a group of in-service teachers to establish validity. Focus group and interview questions targeted teachers' self-efficacy, content knowledge, and dispositions related to STEM teaching and the NGSS. The survey, interview, and focus group questions are shown in Appendix A.

3.4 Data Analysis

This case study research triangulated data through pre and post surveys, interviews, focus groups, and field observations. The survey instrument included 19 questions using a 10-point Likert scale regarding their self-efficacy and dispositions regarding STEM teaching, and is reported descriptively. The four interviews were recorded and transcribed using member checks for accuracy. The two focus groups were recorded and transcribed and checked by a third party for accuracy. The focus group and interview data were analyzed by coding to identify themes. The coding process was guided by the theoretical framework. As such, key elements of Bandura's social learning theory (e.g., self-efficacy, observational learning) were used to assess what information was important, then coded. Interview and focus group data were analyzed to identify similarities and differences among the participants' responses, then codes were assigned to similar words expressed by the participants, which led to identified themes. Daily field notes were kept noting signs of participant engagement, misunderstanding or frustration, PD content understanding, and peer interactions. The field notes were analyzed by describing and categorizing the observed phenomenon, then coded for themes according to the key theoretical elements.

4. Results

An analysis of data revealed some common themes across the four data sets from the surveys, interviews, focus groups, and field observations. The themes emerged from common wording identified in the various data sets related to the focus of the research question. From these themes we were able to craft a narrative describing the PD experience for the teacher participants. These themes can be seen in Table 1 below.

Table 1. Identified Themes from the Triangulated Research Data

	Theme	Participant Statements/Phrases
Theme 1	Confidence in ability to teach integrated STEM lessons	*I can do this…* *I am going to use this…* *My kids will love this…*
Theme 2	Confidence in ability to teach engineering concepts	*I understand the "e" process…* *We can fix that…* *Our design is…*
Theme 3	Confidence in ability to locate STEM resources and teaching strategies	*I love this website…* *What a great idea!* *I didn't know that was there…*
Theme 4	Confidence in personal knowledge level of STEM content	*I know…* *I can…* *I understand…*

4.1 Descriptive Survey (Pre and Post)

Teachers were asked nineteen survey questions using a 10-point Likert scale to determine their self-efficacy regarding STEM content within their curriculum. Pre and post surveys were administered, and all participants responded anonymously. Selected questions were chosen to highlight the important themes related to the research question and are displayed in Table 2.

Table 2. Descriptive Pre & Post Survey Responses for K-12 Science Teachers

Key: A = Not at all / A Little *(Levels 1-3)*
B = Moderately *(Levels 4-6)*
C = Very / Extremely *(Levels 7-10)*

Question	Percentage of Participants	Percentage of Participants
7) I am confident in my ability to incorporate STEM activities for my students.	Pre N = 26 A = 12% B = 42% C = 46%	Post N = 24 A = 0 B = 12.5% C = 87.5%
14) I feel confident in my abilities to teach engineering concepts with my students.	Pre N = 26 A = 23% B = 38% C = 38%	Post N = 23 A = 0 B = 35% C = 65%
6) I am knowledgeable about strategies and resources for implementing STEM into my curriculum at this time.	Pre N = 26 A = 31%	Post N = 24 A = 0

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	B = 42%	B = 21%
	C = 27%	C = 79%
10) I am confident in my knowledge level of STEM content.	Pre N = 26	Post N = 23
	A = 15%	A = 0
	B = 35%	B = 17%
	C = 50%	C = 83%

These descriptive statistics show an increase in confidence and teacher efficacy in all four questions presented from before the PD experience to after the experience. These four questions represent the focus of the research with measuring teacher confidence in their ability to plan STEM lessons, ability to teach the engineering piece of STEM, ability to locate resources for teaching STEM, and their STEM content knowledge. At a quick glance, what stands out the most is the elimination of the lowest two levels (not at all, a little) in all four questions after the PD. In Question seven, participants responded with a 41.5% increase in the highest category (very, extremely) with only 46% feeling confident to plan STEM lessons at the beginning to 87.5% feeling very confident afterwards, which is addressed by theme one. Participants indicated a 27% increase from pre to post in the highest category on question 14 regarding their efficacy in teaching engineering to their students, addressing theme two. The largest increase (52%) in the highest category came in question six regarding teachers' confidence in strategies and locating resources for STEM instruction as identified by theme three, with only 27% of participants feeling very confident prior to the PD and 79% feeling very or extremely confident after the PD. The last question displayed here addresses theme four where question 10 showed the second highest increase of 33% regarding their confidence in STEM content knowledge with only 50% indicating the highest two categories versus 83% after the PD. These descriptive statistics are valuable as they indicate a positive increase in teacher self-efficacy for both content knowledge and planning STEM instruction.

5. Interviews

The interviews revealed some information represented by the identified themes across the four workshop participants that were interviewed. Related to theme one was question five: *How prepared do you feel you are to plan STEM lessons for your students*? The common theme conveyed that the participants felt comfortable teaching the science content, but less comfortable teaching the new integrated STEM components, particularly the engineering design piece prior to the workshop. However, all participants stated that they felt more knowledgeable as a result of participation in the PD workshop with one teacher stating: "I feel somewhat prepared, and after workshops like this one, I am feeling more prepared all the time. I would say a 7 out of 10 maybe". A question directly related to theme three was question seven which asks: *How confident are you in finding STEM resources to help you plan lessons*? The common theme that appeared in this question was that participants stated prior to the workshop they lacked confidence in locating STEM resources, but as a result of the workshop (which provided the teachers with numerous online and print resources) they indicated that their confidence was growing. One teacher stated, “I am beginning to find more and more online resources, so my confidence is growing. This workshop has introduced me to even more resources, so I guess I am still developing”. Question ten asked: *What challenges have you faced in your STEM implementation activities with your students*? The strongest common response presented by the participants was lack of money for materials and lack of time for planning. The last related question we would like to highlight is question eleven which states: *How have your students responded to the STEM lessons you have implemented (prior to this workshop)*? All interviewed participants stated that their students loved the STEM lessons previously taught and were very enthusiastic and engaged when they did them. However, it was still a rare occurrence. One teacher exclaimed, “They LOVED them! Hands-on STEM lessons definitely keep all kids engaged and on task for the most part!”

5.1 Focus Groups

The focus group data revealed commonalities related to the identified themes regarding the teacher participants’ self-efficacy and dispositions towards STEM instruction. Commonalities that emerged from question two, *what would help you to incorporate more STEM activities in your classrooms,* were indicated as threefold, money for supplies, PD, and a STEM curriculum with provided materials. One participant stated,

Well I think that, since I work in [an urban district] and the money is low, if we had supplies, then that would definitely help. Even if it’s something that’s not that expensive, if I am always going out and buying things, it ends up being you know… and we don’t have supplies at our school. Everything ends up being…I mean, paper, that’s it. I think that would be super helpful. (Participant 1)

Question five was directly related to theme one: *How prepared do you feel you are to plan STEM lessons,* were that the participants all felt more confident as a result of the workshops. One participant stated, “I have had to teach science and math in all of them [science classes], and technology as well…so it is the engineering portion that I have to make sure that I address when teaching STEM”. Question eleven targeted theme one: *What are your feelings regarding STEM instruction as a result of these workshops,* a level of excitement and high motivation was depicted with responses such as “I can’t wait to do this [STEM lessons] with my students!”, “My kids are going to love it [STEM lessons]”, and “I like that I can add more STEM activities to my curriculum!” Information was gathered regarding theme two in question 13, *Do you feel confident in your abilities to connect to engineering in your STEM lessons,* where the participants felt that as a result of this workshop, they were gaining confidence in this area. One participant stated:

I thought the workshop provided a lot of resources to allow me to teach it [engineering]. Like I was looking at the Virginia one, the Virginia Coalition website you showed us, and I pulled up a whole lesson, like I could do this! I could print everything out and I could just follow the directions, so I think that from the resources you gave us, I feel very confident about the fact that I can now add more STEM activities in. (Participant 2)

5.2 Field Observations

The researchers were both PD instructors and participant observers during the three-day workshops. At the end of each day, the researchers recorded field notes regarding their observations of the STEM activities and teacher responses and engagement levels. Informed by the social learning theory, analysis of the field notes resulted in connections to the identified themes pertaining to the research purpose of identifying the impact of the PD on participants' self-efficacy for STEM teaching and content knowledge. During the STEM workshop activities, the K-12 teachers were fully engaged in all of the integrated STEM activities. They were able to make consistent connections as to how they would implement the different activities presented into their own curricula. For all of the teachers present, it was indicated that the workshop provided their first introduction to the new NGSS standards. For the large majority, it was also their first introduction to engineering design challenge lessons that fully incorporated an integrated approach to STEM. The participants appeared to fully enjoy the hands-on integrated STEM activities and were actually competitive at times. When engaged in the Mars parachute challenge, the teachers were competitive in designing the best parachute with the slowest drag time. Just as in the interviews and focus groups above, expressions such as "I love this!", "This is so much fun!", and "I can't wait to do this [STEM lessons] with my students!" were heard throughout the sessions. Teachers were captivated during their time in the Discovery Museum and Planetarium as well. The NASA Mission Control simulation was truly impactful as the teachers experienced exactly what their students would experience if/when they came to the museum on a field trip. The teachers were enthralled with the *Science on a Sphere® (SOS)* demonstration at the museum. They were excited that the SOS software is available as a free download and many stated that they planned to use this new knowledge of technology in their own classrooms with their students in a 2-D format. Overall, this data confirmed themes one through four as the teachers conduct and reactions demonstrated a positive response in their self-efficacy towards STEM instruction and content as a result of the PD as observed by the researchers.

6. Discussions and Conclusions

The findings from this case study indicate that the teacher participants demonstrated a positive response in their self-efficacy regarding STEM teaching and content knowledge, which was addressed in the research question. These results indicate that the teachers perceived an increase in their abilities to locate STEM resources, plan integrated STEM lessons, incorporate engineering, and gain knowledge regarding STEM content as a result of the PD through triangulated data collection and indicated in the identified themes.

During the focus groups and interviews, participants indicated an increase in their self-efficacy for teaching STEM through their positive statements as well as observation of their positive body language. The teachers shared their excitement in their future implementation of the STEM activities from the workshops as well as using the resources provided to find additional appropriate STEM activities for their particular grade levels. Statements were made by the teachers about the value of the PD and the resources that were provided that would help them implement STEM within their own classrooms, thus demonstrating an increase in their self-efficacy. The pre and post survey data descriptive results were in agreement with these findings, thus strengthening the case study.

During the focus groups and field observations, participants expressed positive dispositions towards teaching STEM as indicated by repeated themes that appeared in the coding process, which were also addressed in the research question. Particularly strong themes that arose were those specifically associated with planning and implementing STEM learning activities for K-12 students as a result of the PD. These results are in agreement with the literature which reports that through quality PD, teachers' self-efficacy and dispositions towards STEM positively increase (Nugent et al., 2010; Nadelson et al., 2013; Wang & Nam, 2015). We can connect the quality of the PD back to Vygotsky's constructivism processes and Bandura's social learning theory as participants experienced the authentic STEM instruction through the modeling of the STEM teaching and through social interaction with their peers on the various challenges presented.

Finally, our findings are in agreement with previous research which indicates offering a PD approach that emphasizes social learning along with engaging hands-on inquiry-based methods is most effective in positively impacting teachers' self-efficacy towards STEM content knowledge and STEM teaching (Richmond et al., 2017; Aslam et al., 2018; Beaudoin et al., 2013; Nadelson et al., 2013; Nadelson et al., 2012). These results therefore validate the goal of this case study as indicated earlier to provide engaging PD for K-12 teachers that enhances their effectiveness in teaching integrated STEM, as addressed in our research question.

6.1 Limitations

It should be noted that one limitation to the study is the fact that teachers self-selected themselves as participants in the PD workshops, thus indicating a possible pre-existing positive disposition towards learning more about STEM teaching and the implementation of NGSS. A second limitation to this study is the inability to measure participants' STEM content knowledge other than self-reporting. For this aspect of the research question we were only able to measure participants' personal response on the survey and pure observation. A third limitation is the reduced generalizability of the case study approach. Consequently, the teachers' reported enthusiasm and self-reported increased levels of self-efficacy should be interpreted with caution.

6.2 Future Research

The researchers would be interested in conducting a series of collective case studies on the impact of quality PD on STEM teaching longitudinally. It would be interesting to measure the direct impact of the PD on science teachers' actual implementation of the STEM teaching strategies learned within their own classrooms in the months following the PD workshops. One could also improve the measure of teachers' learned STEM content knowledge by imbedding content questions on the pre and post survey, however, this may intimidate some participants.

"All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards".

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