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In-service Teachers' Implementation and Understanding of STEM Project Based Learning

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In this study, we discussed the participating teachers' implementation and understanding of science, technology, engineering and mathematics (STEM) project based learning (PBL). A research team at a STEM center systematically offered professional development activities to 92 teachers in an urban school district in the southern U.S. To investigate the teachers' implementation and understanding of the STEM PBL pedagogy, we conducted a collective case study with five teachers. Study data included interviews, in-class observations, and lesson plans designed and implemented by the teachers. The results of this study indicated that the PD sessions were effective in communicating several important concepts about STEM PBL. Nevertheless, our observations revealed that five teachers' classroom enactments did not necessarily convey their understanding of STEM PBL.

Keywords: professional development, STEM education, project based learning, case study.

INTRODUCTION

The role of project based learning (PBL) in science, technology, engineering, and mathematics (STEM) education has gained much interest since the beginning of the 21st century (Thomas, 2000). STEM PBL instruction is quite different from knowledge-centered, traditional instruction because it requires the teacher to fully comprehend its pedagogical orientation for successful teaching practice. Effective professional development (PD) can help teachers acquire the necessary pedagogical skills to implement STEM PBL (Capraro et al., 2014). Understanding how to effectively implement STEM PBL plays a major role in how teachers teach and the ultimate learning experiences of students. Research (Capraro et al., 2014; Darling-Hammond, 2000; Darling-Hammond & Youngs, 2002; Goldhaber, 2002; Rice, 2003; Wayne & Youngs, 2003) has shown that students learned more from skilled and experienced STEM PBL teachers, whereas teachers who ineffectively implemented PBL instruction had a negative effect on students' performance. In-service teachers should be informed about the effective pedagogical strategies for implementation of PBL activities and be guided to design and implement STEM PBL lessons preferably through sustained PDs.

The purpose of this study was to explore teachers' understanding and implementation of STEM PBL activities using a qualitative case study approach. Exploring teachers' understanding and implementation

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State of the literature

- Teachers' understanding and implementation of STEM PBL has greatly affected students' content understanding and developing skills.
- Students learned more from skilled and experienced STEM PBL teachers, whereas teachers who ineffectively implemented PBL instruction had a negative effect on students' performance.
- The teacher's role in implementing STEM PBL must be different from the one in traditional classrooms and effective PD can help teachers acquire the necessary pedagogical skills to implement STEM PBL.

Contribution of this paper to the literature

- The results of this study indicate that the PD sessions were effective in communicating several important concepts about STEM PBL.
- Teachers sometimes presented different enactments from what the PD providers intended. Some teachers did not change their instructional strategies and other teachers acquired misconceptions.
- STEM PBL is a fairly new instructional pedagogy and teachers had a variety of challenges in implementation, even though PDs, seminars, and conferences on STEM PBL were provided for these teachers.

of STEM PBL activities was necessary to evaluate the impact of the sustained PDs provided for the teachers and to examine the quality of students' STEM PBL experiences in enacted classrooms. Thus the research question explored through this study was, "After sustained PD on STEM PBL, what were the participating mathematics and science teachers' understanding of and attitude towards STEM PBL and how did they implement STEM PBL in their classrooms (enactment)?"

Defining STEM PBL

Two central trends define PBL in the literature; (a) Kilpatrick (1918)'s *project method* and (b) the reform movement in early 21st century. The STEM PBL as defined in this study was within the boundary of the progressive education reform movement, which was more willing to apply PBL in K-12 education. PBL pedagogy before the 21st century was mostly implemented in postsecondary education classes and in the medical and engineering fields (Steipen & Gallagher, 1993). PBL might be defined more clearly by comparing it with problem based learning. In PBL, students had more autonomy to drive and investigate the problems on the basis of ill-defined tasks, while in the problem based learning, the research questions and the context of the problem were provided for them (Slough & Milam, 2013).

STEM PBL has been defined as "a well-defined outcome with an ill-defined task" (Capraro & Slough, 2013, p. 2) and used as a student-centered instructional methodology (Bransford, Brown, & Cocking, 1999). STEM PBL is not only an instructional approach using a project at least two of the four STEM subject areas, but also includes teaching orientation grounded in constructivism and constructionism. A STEM PBL activity is interdisciplinary in nature and requires students to locate and define a problem as they explore a project topic (Capraro, 2013). Rather than a teacher telling students what to do, students work in collaboration with their peers to identify the problems and find strategies to solve within STEM PBL activities (Ozel, 2013). Students have opportunities to construct their own knowledge with deep understanding of the disciplines in STEM PBLs, rather than traditional classrooms where teachers disseminate content knowledge (Ozel, 2013). The goal of STEM PBL has been to help students acquire deep content understanding and skills along with developing feelings of commitment and ownership of their learning (Barron et al., 1998).

Perspective on Professional Development

PD has been often viewed as a specific training offered by some educational specialists at a limited time and location (Guskey, 2003; Roesken, 2011). However, PD occurs every day and everywhere in schools. Teachers can improve the quality of their instruction as they gain more experience in teaching, if and only if, they are willing to self-reflect on their teaching practices and use their metacognitive skills as they iterate their instructional design. Nevertheless, according to Guskey (2003), few teachers were willing to change or modify the design of their instructions. Hence, some mandatory PDs have been recommended.

The teacher's role in implementing STEM PBL must be different from the one in traditional classrooms and should be open to adapting to new principles from reforms in education. The teachers' role should evolve "from [being] lecturer and director of instruction to resource provider and participant in the learning activities; and from [being] expert to advisor/facilitator" (Newell, 2003, p. 5). Even though this statement is easy to comprehend, it is not easy for most of the teachers to take the advisor/facilitator role in their teaching practices.

Teachers' understanding and implementation of STEM PBL has greatly affected students' content understanding and developing skills (Capraro et al., 2014). Students learned more from the teachers who were qualified and had profound content and pedagogical knowledge (Darling-Hammond, 2000; Darling-Hammond & Youngs, 2002; Goldhaber, 2002; Rice, 2003; Wayne & Youngs, 2003). This was similarly true in STEM PBL classroom environments where students reported similar effects from their teachers' instructional fidelity. In the STEM PBL lessons, students gained higher scores in the statewide assessment only if teachers showed higher fidelity in implementing STEM PBL. Students, who were provided lower quality STEM PBL lessons, showed a negative growth rate (Capraro et al., 2014). Hence, effective PDs are extremely important for teachers implementing STEM PBL in their classrooms.

Characteristics of effective PD and its components have been researched and discussed. Researchers have investigated the effectiveness of PDs by comparing teachers and students' performances before and after the PD interventions (Garet et al., 2011). Sustainability and intensity were identified as critical features of an effective PD (Capraro et al., 2014; Garet, Porter, Desimone, Birman, & Yoon, 2001; Joyce & Showers, 2002). Sustained PDs in an online environment (Denton, Davis, Smith, Beason, & Strader, 2005), heterogeneous groups (Corlu, 2012), self-evaluation bases (Duff, Brown, & van Scoy, 1995; Guskey, 2003; Whitaker, Kinzie, Kraft-Sayer, Mashburn, & Pianta, 2007), and collaborative professional learning communities (Erickson, Brandes, Mitchell, & Mitchell, 2005; van Es, 2011) were reported as effective for enhancing teachers' skills and knowledge. However, researchers have not investigated how long the impacts of PDs were maintained. Although the effectiveness of PD inferred not only teacher's changes in beliefs and practice, but also the sustainability of the impact of the PDs, the later aspect on the PD's effectiveness has not been studied in detail.

Even though a great deal of funding has been invested in PDs to improve in-service teacher practice, pedagogies in real classrooms have not changed as much as expected (McLeskey, 2011). What teachers learn from PD and what and how much they actually enact in their classrooms might differ (Pfeffer & Sutton, 2000). An expert-centered PD, compared to a learner-centered PD, rarely enabled changes in teaching practices to be realized (McLeskey, 2011). The expert-centered setting indicated a PD that was provided by an outside specialist, who was well known within reformed education (Choy, Chen, & Bugarin, 2006), and teachers were given knowledge on the innovative instructional approaches passively. In contrast, learner-centered PD more actively engaged teachers in the PD activities in hopes of promoting deeper understanding of the innovative practice (Desimone, 2009; McLeskey, 2011). The PD implementation approach influenced the extent to which teachers change their practices as well as beliefs. The expert-centered PD was found less effective in changing teachers' actual instructional approaches than the learner-centered PD (McLeskey, 2011). Therefore, the effectiveness of a PD should be evaluated based on the PD's impact on the teaching enactment in an actual classroom.

As teachers were required to change their teaching practices to adapt to an educational reform movement, they encountered different challenges. In a STEM PBL classroom setting, teachers were expected to exhibit skills and abilities that they were not generally used in a traditional classroom setting. First, teachers needed to share responsibilities with students for classroom management in STEM BPL (Ozel, 2013; Ward & Lee, 2002). Students in the STEM PBL classroom were expected to direct and be cognizant about their own learning and teachers only guided and helped students further their primarily self-focused learning. Teachers had greater difficulties implementing STEM PBL activities if they were primarily accustomed to implementing a traditional instructional approach (Ozel, 2013). Second, teachers were often not familiar working with other teachers in other fields. They had time and location constraints. A STEM PBL should involve interdisciplinary content which is one critical feature of its pedagogical orientation. Teachers should collaborate with other teachers who possibly have different teaching areas, timetables, and teaching philosophies. Teachers needed to spend extra time and effort preparing for a STEM PBL classroom activity. Lastly, teachers had difficulties adapting the characteristics of STEM PBL they learned through PDs into their in-class teaching (Ward & Lee, 2002). A top down approach has generally been used in offering PDs. In other words, university faculty or governmental agencies usually delivered the PDs to teachers. Teachers had additional barriers in attempting to implement STEM PBL instruction in their classroom because they barely gained any sufficient practical experience from PD trainings (Ward & Lee, 2002). An effective PD should provide sufficient practical experiences in enacting STEM PBL activities into classrooms.

Context of the Study

In Texas, the Texas High School Project started in 2007 as an emphasis on STEM education for secondary students, and involved 51 high schools. Seven Texas Science, Technology, Engineering, and Mathematics (T-STEM) centers were created to deliver PDs on STEM education for teachers in district schools. The primary mission of the T-STEM centers was to design and implement PDs helping to improve students' readiness for postsecondary majors and professions especially with low-income and low-performing students in STEM fields. This study focused on the PD provided by one T-STEM center to 92 teachers. The teachers attended a sustained period of PD (10 sessions per year, seven hours per session) over a three-year period. The participants were recruited from three schools –one charter school and two STEM academies.

The main purpose of PD was to assist in-service teachers in implementing STEM PBL activities in their classrooms. The focus of the PDs was designed to improve teacher's instructional skills in integrating content knowledge on STEM. In the beginning sessions, training content focused on the development of the theoretical framework and philosophical background of PBL. In the later sessions, teachers were provided opportunities to learn best practices of STEM PBL and to ultimately design STEM PBL lessons for their individual classrooms. In the process of designing STEM PBL lessons, teachers were grouped according to project topics, subjects, grade levels, and schools. Teachers had the opportunity to receive structured and open-ended feedback on their lesson plans from PD providers and colleagues. The STEM PBL lessons were fundamentally based on mathematics and science content; but also included technology and engineering content.

The student population in the three schools was mostly Hispanic and African American (91.8%), and was categorized as economically disadvantaged (85%) (i.e., students who were eligible for free and reduced-price meals) and at-risk (62%) (Texas Education Association, 2011). The overarching goal of the T-STEM center was to improve the students' 21st century skills (e.g., communicating, collaborating, creating and innovating, finding and evaluating information, analytical thinking, and problem solving) with particular emphasis on the economically disadvantaged and low-performing students in the STEM fields.

Teachers' attendance in the PD sessions was mandatory because of a district mandate to implement PBL activities into classrooms. Teachers were generally receptive to the district-wide PD focus and their curriculum coaches served as liaisons to the PD providers. During the PD sessions, teachers were informed about the engineering design principles of STEM PBL and guided in preparing interdisciplimary STEM PBL lesson plans in advance of enactments. Teachers were requested to implement STEM PBL lessons in their classes once every six weeks over the school year. Among the 92 participating teachers, five teachers were selected and more deeply examined for this study.

METHODS

This study aimed at capturing inservice teachers' understanding of STEM PBL and how they organized their classroom instruction accordingly. Participating teachers involved in the study had an individualistic view of the STEM PBL learning environment based on personal experience. A qualitative case study approach provided the opportunity to delve deeply into the rich information of the case (Creswell, 2007; Denzin & Lincoln, 2005; Yin, 2003) and was appropriate in situations where variables could not easily be identified and theories were not available to explain all behavior (Yin, 2003). This collective case study with multiple cases (Stake, 2005) was augmented with a descriptive case study design (Yin, 2003). Each teacher represented a single case and all five teachers described one common issue. In addition, case study was appropriate in explorations over time and involving multiple sources of information rich in context. The data of teachers' participation in PD, lesson plan, and implementation of STEM PBL was collected longitudinally by using diverse protocols.

Participants

Five in-service mathematics and science teachers (pseudonyms: John, Chira, Susan, Linda, and Robert) were purposively selected from the 92 participating teachers to respond to the research questions. All five teachers participated in the sustained STEM PBL PD activities. The two male teachers (i.e., Robert and John) were White. Two female teachers (i.e., Linda and Susan) were White and one (i.e., Chira) was Asian-American. Linda, Robert, John, Chira, and Susan taught environmental systems, precalculus, algebra, algebra, and geometry, respectively at the time of data collection (see Table 1).

Data Collection

A team of researchers at the STEM center observed the teachers' STEM PBL enactment and conducted individual interviews. Four teacher educators, four graduate students, and one center manager were the members of the research team. Every member of this research team had majors in STEM fields and were trained in observing and evaluating teachers' classroom enactments of STEM PBL activities. Data sources were (a) each participant's lesson plans, (b) an in-class participant observation, and (c) one-on-one semi-structured interview. The teachers designed their lesson plans prior to their classroom implementation and shared the documents with the content experts at the STEM center. The lesson plans were analyzed and characterized by the pedagogical orientation embedded in the lesson design. Each class observation lasted 50 minutes and the evaluation instrument developed by Stearns, Morgan, Capraro and Capraro (2012) was completed during the observation. The observer asked

Table 1. Teachers' demographic information

Participant Name	Sex	Ethnicity/Race	Teaching Experience at the time of data collection	Subjects taught at the time of data collection
John	Male	White	11 years	Algebra
Chira	Female	Asian-American	7 years	Algebra
Susan	Female	White	21 years	Geometry
Linda	Female	White	27 years	Environmental systems
Robert	Male	White	2 years	Precalculus

the students in class several questions and recorded their responses to further analyze and verify them with the teachers' implementation of STEM PBL. The five teachers who participated in this study were invited for individual interviews. All agreed to participate. In the interviews, questions were asked about their experiences in teaching and their enactment of STEM PBL activities in their individual classrooms. Each interview lasted for around 30 minutes. The interviews were audio-recorded on an I-Pad and the recorded conversations were transcribed verbatim. The designed interview protocol was semi-structured and so some emerging questions were asked during the conversations. The protocol included the following questions:

- *What do you think about STEM PBL?*
- *What do you think about the impact of the STEM PBL on a teacher's instructional method?*
- *How do you implement STEM PBL activities in your classroom?*
- *How do you evaluate your STEM PBL activities in your classroom?*

The first question sought the interviewee's personal opinion about STEM PBL. The intent of the second and the third questions was to to capture the participants' understandings and implementations of STEM PBL. The fourth question helped triangulate the participants' understanding of the purpose of STEM PBL instruction.

Data Analysis

The qualitative data were collected and analyzed to determine themes (Creswell, 2007; Denzin & Lincoln, 2005). Data sources included the teachers' lesson plans, observation descriptions, and interview transcriptions. The research team reviewed the teachers' lesson plans using a rubric for lesson plans developed by the two authors and provided feedback to the teachers (See Appendix). Lesson plans signaled teachers' understandings of STEM PBL and their perception of STEM PBL implementation in class. The findings from the lesson plans were utilized when comparing the teachers' understanding of STEM PBL and their in-class implementation. The observation findings were triangulated with the interview findings. Descriptions written by the observer were referenced during the interview and compared to the teachers' interview responses. The transcribed conversations with the five teachers were analyzed (Stake, 2005) in three steps. The first author transcribed the recorded conversations and an external peer reviewed the transcriptions for accuracy. Next, the transcriptions were read several times and the research team performed open, axial, and selective coding (Glaser & Strauss, 1967). That is, an organized and systematic process was developed for the emergent themes from the qualitative data. The initial step was open coding, that was a process of identifying essential elements, examining, comparing, conceptualizing and categorizing data. It was data reductionist in nature and an inductive process. Open coding consisted of discovery that included labeling phenomena, categorizing developing categories with similar properties and characteristics. Axial coding follows and it is the assembly of the results from open coding in new ways. The purpose was to make connections between the discovered categories. With axial coding there was a transition from inductive data analytic methods to deductive. For example, data that helped develop the categories were examined for the purpose of identifying the conditions that gave rise to it. The most common reasons for axial coding were to search for causal conditions and a contextual rationale. Causal conditions were those that reasonably precipitated the occurrence of the category. With contextual rationale the goal was to identify the set of properties that pertain to the category. The third and final step was selective coding. With selective coding the goal was to determine the essential, central, or core category. The outcome of the selective coding was to validate the narrative.

FINDINGS

All teachers implemented STEM PBLs in science and mathematics classes and demonstrated varied understandings and enactments of STEM PBLs.

Case 1: John

John was in his 11th year of teaching high school mathematics. He had attended PD sessions since 2008. He collaborated to develop the STEM PBL lesson plan with Chira. He believed that STEM PBL was more likely to help students review what they learned, rather than assisted them in understanding new concepts. This belief was why he picked a topic that students were being taught for one and a half months. John designed the lesson plan using STEM PBL for the review of the topic. The well-defined outcome described in his lesson plan was "The student will make a connection between quadratic formula and the real world." He tried to let students apply mathematics formula to the real world situation and introduced the scenario.

My friend is in trouble. She is an architect and her boss is angry because she could not explain the mathematics behind the bridge she designed. Can you help her? Give an example to help show her how you see quadratics in the world around you. (John's lesson plan)

John represented a skeptical perspective to doing STEM PBL with regular students. He believed that STEM PBL was not effectively working with regular students, because regular students were not ready to do STEM PBL.

I think for my pre AP kids, it [STEM PBL] is very good for them. For regular kids, there are a lot of behavior issues. … They are excited about projects because they could hang out and just talk and have a good time, but not do the actual assignment. (John, March, 2011)

Based upon his interview comments, John strongly believed that teachers' participation in the STEM PBL classes should be minimum. His perception of the teacher's role in STEM PBL classroom had been changed since his previous experience.

I think with the PBLs, let them [students] know it, give them the tools or resources to solve it [problem] and then just kind of steer them from that all. Let them do the driving and let them do the actual learning part. My role I felt during the project was just to kind of guide them and say about this, that's really good or work on this or what so ever. In the first PBL that we did, I was all the more hands on and I think it kind of hindered their ability to think for themselves because they would ask me, 'Is this okay?' and I would say 'Yes, that's good.' Here, I was more like yeah, they could work, and I was little more hands off. (John, March, 2011)

In his class, John actually circulated around to students' tables and talked to the students for the first ten minutes. Next, he sat at his desk and did not interact with students until the class was over.

John pointed out one challenge in implementing STEM PBL in his classroom. John reported that the miscommunication between teachers and PD providers caused several PBL projects to be implemented on the same class days, which caused stress for the students. Because the PD observers, including the interviewer, were present in the school on the same day, the teachers in each subject area had to implement their STEM PBL lessons simultaneously. John believed that this situation negatively affected student performances as the time constraints hindered students' complete involvement with the STEM PBL project activities.

Case 2: Chira

Chira was in her 7th year of teaching high school mathematics. She had been involved in the STEM PD sessions since 2008. As indicated before, she collaborated to develop the STEM PBL lesson plan with John. She defined "project based learning as interdisciplinary" and believed in the positive impacts of STEM PBL on student development of conceptual understanding on mathematics contents.

What I feel about project based learning is, more than the content, the skills are developed. That's what is more important with the project based learning, because you can always like teaching them the content. They use the content or the concept but the skills that they develop can be transacted to other concepts. … I would say like the content would be the quadratic formula itself, but then the skill would be to learn how to plug in or how to identify what's a quadratic equation, how to identify A, B, and C. (Chira, March, 2011)

Compared to John, Chira displayed different teaching behaviors, even though they had the same lesson plan and their basic ideology of a teachers' role in STEM PBL classes had some common qualities. In contrast to John, Chira continually circulated to students' tables while answering students' questions. She was always observing what students were doing.

Chira had detailed ideas and plans concerning the evaluation of students' activities during STEM PBL. For the formative assessment of STEM PBL, Chira continuously recorded students' work and their behaviors during the class as she graded students individually. That is, she evaluated the procedures of the project as well as the final outcomes. Furthermore, she divided the evaluation portion into two sections: an individual grade section and a group grade section. Individual grades were awarded by the amount of work students completed during the project, whereas group grades came from the content's correctness, relativeness, and creativeness, and presentation skills (e.g., clear voice and eye contact with his/her audience).

As John did, Chira also had negative perceptions on the students' readiness to do STEM PBL. She pointed out that students were not always interested in the goals

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or tasks, and characterized her students in the STEM PBL class as "When it's implemented, there is neither engagement nor student talk about the topic."

Case 3: Susan

Susan was in her 21st year of teaching high school mathematics. She had participated in PD sessions since 2008. During the interview, Susan shared how eager she was to implement STEM PBLs in her classroom. Based upon the interview it was determined that Susan was enthusiastic to attend PDs and to implement STEM PBLs.

> *I like PBL. I can't say I every do have perfect job at doing implementation of it, but I like designing things. I mean, if I haven't been a teacher, I would probably be an engineer. I would like creating things… I don't mind to creating PBLs. I think that's actually, kind of interesting thing that makes me think and makes me kind a try to see I can tie things together. (Susan, March, 2011)*

Susan regarded STEM PBL as an instructional strategy connecting mathematics contents to the real world, and encouraging students to have more interests in learning mathematics. She stated "It [PBL] is a way to get kids involved in mathematics just in a different way… just to get them touching and feeling in mathematics." Her STEM PBL was called "Thinking outside the quadrilateral", which was connected to the real world and included hands-on activity, taking pictures. Students were asked to research quadrilaterals assigned and take pictures around the school of real world examples of those quadrilaterals.

Based upon comments and further elaboration on her students at the school, Susan indicated that teacher roles in classrooms have changed due to student characteristics. Basically, she assumed that current students were different than students in the past.

> *Back then, students would do with book, paper, and pencil, because you ask them to do. But, kids have changed over the years. In the past, students would solve problems using paper and pencil, whereas current students do not do that. So, it's the different client now. (Susan, March, 2011)*

Students in the past were obedient and had better concentration powers with less need for constant motivation. However, current students need to be stimulated with diverse materials from various sources and the teachers need to constantly encourage them.
Susan thought student interest was critical for success in implementing STEM PBL. Susan had knowledge of her students, which was applied on her lesson. According to her comments on the students, she realized that her current students need lots of motivation with diverse materials, not just with paper and pencil. In the beginning of her STEM PBL, Susan presented a video clip describing students' absences and boring classes and encouraged students to plan an interesting presentation on quadrilaterals for students who were absent. In addition, she employed an essay component in mathematics class for students, because the majority of students in the school were Hispanic and English as a Second Language (ESL). In the class that the authors observed, all students were focusing in class and were eager to explore the problem of designing lessons for absent students.

In spite of her positive attitude toward STEM PBL, her actual implementation of the STEM PBL conveyed that she considered the STEM PBL as a supplementary instructional method. She designed her STEM PBL activity to be completed in two full days; however, because of a test preparation, she postponed implementing the STEM PBL on the second day. This indicated that she viewed the STEM PBL as supplemental and not of primary importance for her students.

Case 4: Linda

Linda was in her 27th year teaching high school science. She had been involved in STEM PD sessions since 2008. Linda was eager to learn about STEM PBL and implement it in her classes.

> *I have been attended all of them [PDs]. This is my third year in it. So, my questions are going to be more in depth than the first time working with PBL. I think it added each time to what I have worked. (Linda, March, 2011)*

She designed an interdisciplinary STEM PBL lesson plan combining environmental systems, English, mathematics, and social studies. She has taught varied subjects of science such as biology, chemistry, and environmental science. Through the experience in teaching diverse science subjects, she designed STEM PBL that engaged students with their prior knowledge and culturally diverse contexts.

Linda identified herself as an expert with the basic contents of STEM PBL and emphasized a deep understanding of STEM PBL was necessary for an implementation, "Better understanding with PBL, the better you can write one [lesson plan] and do one." She emphasized that teachers were required to have a 'big picture' on the topic that they were going to cover across six weeks before designing STEM PBL lesson plans.

> *It is easier to implement when you have a big picture. Because there is a framework, then I can put a PBL in. If you do not understand the framework, the PBL is hard to do. So, when I knew the topics that were going to be covered in the six weeks, I could find one that the PBL was better at getting the information across in. Some topics are so good for PBL, other not so good. When you have the big picture, then the PBL is very helpful. (Linda, March, 2011)*

Linda had been teaching different science subjects each year. Therefore, it was more difficult for her to prepare the STEM PBL lesson because the subject, environmental systems, was new, and different from other science subjects such as biology and chemistry. Linda needed to spend more time to prepare the STEM PBL lesson because there has been very little accumulative information related to the environmental systems. That is, she considered that a preparation of STEM PBL was not a difficult task for teachers who were teaching subjects more familiar to them.

Linda believed that student's readiness for STEM PBL was critical in implementation. She stated, "This [STEM PBL] works much better with an older group where you can expect more out of them than you would in a freshman class." Linda thought that student's readiness is the key for the successful implementation of STEM PBL. Therefore, Linda evaluated the students' daily reports individually and the poster presentations as a group. Nevertheless, the students in Linda's classroom could not understand how the rubric would be used as an assessment, even though Linda explained a rubric she designed to evaluate the students' posters and oral presentations. Linda commented on her communication with the students as,

So what do we have to have by Friday? Then they [students] became more concerned about the rubric and what was going to be graded. Because the first—middle of it—by the second day, they were not too worried. Some of them were not worried at all, even at the end. (Linda, March, 2011)

Linda expected her students to be concerned about the evaluation rubric for the STEM PBL lesson. However, her students were not as concerned about the rubric and how teachers would evaluate them as she expected.

Case 5: Robert

Robert was a second-year high school mathematics teacher. Although Robert was still a novice in implementing STEM PBL, he held strong beliefs concerning STEM PBL. He was certain that STEM PBL should reflect students' future as well as present lives.

The purpose of that [STEM PBL] was obviously to find their annual salary –the average annual salary. So they could create budget. … They [students] had a lot of really looking to the future. A lot of them are really how this is coming up. And so that is a good thing. (Robert, March, 2011)

Therefore, Robert's STEM PBL lesson plan actually was associated with students' future professions and income. The well-defined outcome on his PBL lesson plan was,

The student will select an irregularly shaped plot of land in McLennan County to purchase and then research plans to build a house. The student will use Law of Sines to determine the area of the irregularly shaped plot of land, determine the cost of the land using McLennan County Tax Rates, select a house plan to build on the land, and make a scale drawing of the land and the house. The student will then research his or her desirable profession, make a budget (pie chart), use TVM formulas, and determine whether he or she can afford to purchase the mansion. The student groups will present their projects to their peers. (Robert's lesson plan)

However, Robert showed several implementations that did not match to the designed lesson plan. Critically, his STEM PBL did not include rigorous mathematics content in the observed class, even though he was teaching precalculus. His understanding of the interdisciplinary nature of the STEM PBL led him to apply other subjects' content in the mathematics class; but he missed teaching mathematics along with the other subjects in his designed STEM PBL. In addition, Robert did not assign his students into groups for the project, even though he had the indicator, "collaboration with peers" in the project rubric, and the statement, "The student groups will present their projects to their peers" in the lesson plan. Based upon his comment on group work, Robert preferred the students to work individually to estimate their future salaries, which was a part of well-defined outcome of the project.

I haven't work individually on the career for what you saw [PBL]. They were working individually. They asked why they couldn't work in groups and I said you are not going to work in groups, like you are not going to take someone else with you. …Also, I don't want them to combine their interests with someone else's. I want them to look at their futures because they are seniors and they are about to graduate. (Robert, March, 2011)

As a brand new teacher, Robert made several mistakes enacting his STEM PBL. First of all, he forgot passing the hand out and the project assessment rubric to the students. When the researchers asked students whether they understood how their presentations would be evaluated, they could not answer. In addition, Robert did not check the computer to make sure that the PowerPoint would run appropriately. Robert did not possess much knowledge about the STEM PBL and his PBL lesson was not well organized.

Robert displayed low confidence in his students, an attitude similar to John's. He said that "my kids really were not ready to start the PBL" and believed that students may not be interested in knowing about the critical components of the STEM PBL instruction that focused on learning goals and assessment rubric criteria. This attitude could explain why Robert provided students elementary instructions that were easy to follow. Nevertheless, students' self interests in the topic were very high and they completed the project with enthusiasm.

DISCUSSION

The teacher is a critical factor for implementing any educational reform, including STEM PBL. However, there have been very few research studies that have investigated what teachers learned from PDs on STEM PBL and how teachers practically enacted and adapted their learning into classroom settings. To develop a more effective PD on STEM PBL in practice, it is crucial to examine teachers' understanding and implementation of STEM PBL. The illumination of the relationship between teachers' understanding and implementation of STEM PBL should be investigated, because what teachers implement in their classrooms may be different from what they learn from the PDs provided for them. The ultimate goal of the PDs on STEM PBL was to lead teachers to utilize their learning from the PDs into their classroom lessons in appropriate ways. In this sense, educators need to investigate how well teachers adopt and implement educational reform into their lessons, not just provide PDs. Even though the current study could not compare teachers' pre- and post-attitudes toward, and understanding and implementations of STEM PBL due to the limit of data, this study contributes to knowledge about the impact of PDs on teachers' instructional conceptions and practices of STEM PBL.

New Conceptions of STEM PBL Learned from PDs

The results of this study indicate that the PD sessions were effective in communicating several important concepts about STEM PBL. For example, the teachers in the study recognized that education reforms, such as STEM PBL, required a different set of pedagogical abilities compared to traditional classrooms through PDs (Barron et al., 1998; Capraro & Slough, 2013; Newell, 2003; Ozel, 2013). The teachers in this study were able to understand and explain what STEM PBL was in comparison with the knowledge-centered or teacher-centered instruction. Most teachers observed in this study acknowledged that STEM PBL was critical and effective in stimulating students' interests and improving students' understanding of content.

Implementing STEM PBL required a change in teachers' educational pedagogical "bag of tricks." Even though STEM PBL is grounded in constructivism, which was developed by Dewey (1938) and Kilpatrick (1918), teachers have demonstrated that they are not comfortable with student-centered learning environment. According to Joyce and Showers (1980), the PD in this study was more focused on "learning new ways of teaching," rather than "tuning the present skills" (p. 379). To effectively implement a new instructional strategy, teachers need to explore and understand its rationale, think differently, and behave differently (Joyce & Showers, 1980, 2002). The five teachers in this study illustrated different conceptual understanding of STEM PBL using a traditional classroom lens. The teachers' STEM PBLs included more practical purposes, their tasks covered diverse subjects, and fewer instructions were provided than a traditional classroom. All five participants considered STEM PBL an interdisciplinary activity in nature. Their lesson plans included two or more subject areas (e.g. art, technology, social studies) in addition to either mathematics or science content. Moreover, a common purpose of using STEM PBL activities that emerged from the analyses was connecting mathematics and science with the real world. For example, in a STEM PBL activity Robert designed, students were asked to estimate their future salaries and budget. In her lesson plan, Susan indicated a well-defined outcome, "Student teams will be able to identify two different quadrilaterals they have been assigned; discover their properties, similarities, and differences; and find quadrilaterals in the real world." Lesson plans designed by Linda, John, and Chira applied culturally diverse contexts related within the students' lives.

Finally, the teachers recognized their different roles in STEM PBL classrooms compared to traditional classrooms as consistent with Newell (2003). They believed that STEM PBL classes were organized differently from traditional classes and teachers were assigned particular functions. John defined his role in STEM PBL classes as a "guide," while Chira defined hers as a "facilitator." Thus both of their classes were less teacher-directed. Susan specifically pointed out that a teachers' role during STEM PBL should be different from that of traditional classrooms, because students, materials, and curriculum have changed even though content topics and objectives are similar.

Teachers' Understanding vs. Implementation of STEM PBL

Teachers sometimes presented different enactments from what the PD providers intended. Specifically, 1) some teachers did not change their instructional strategies and 2) other teachers acquired misconceptions.

As indicated in the study by McLeskey (2011), teacher practice was less changed than their conceptions on STEM PBL, even though PD sessions observed in this study were more learner-centered than expert-centered. The gap between knowing and doing existed in the observed STEM PBL classrooms (Pfeffer & Sutton, 2000). In this study, the gap between knowing and doing was better described as the gap between believing and knowing STEM PBL, and the gap between doing and showing STEM PBL.

Teachers demonstrated a conflict between believing and knowing STEM PBL. For example, even though the teachers in the PD sessions generally knew the positive effectiveness of STEM PBL, they still regarded STEM PBL as an obstacle to preparing for summative statewide tests. The findings of this research also suggested that there was a contradiction between teachers' perceived notions of the effectiveness of STEM PBL. In other words, teachers revealed their beliefs that STEM PBL might improve student understanding of content; on the other hand, they tended not to expect student scores on summative tests to be higher after engaging in STEM PBL lessons.

Moreover, teachers exhibited a gap between doing and showing STEM PBL. According to Showers & Joyce's (1980) levels of PDs impact, the PD in this study influenced teachers' awareness, concepts and organized knowledge, principles and skills, and even practice and application of the trained instructional strategy. That is, the PD activities helped not only improve teachers' pedagogical knowledge and perception on STEM PBL, but also supported them in applying what they learned in the classroom. However, based upon the designed lesson plans and conversation during the interviews, Robert and John tended to do STEM PBLs for show, rather than adopting STEM PBL into their daily classroom instructional routines. If the implementation of STEM PBL was not required, they most likely would not complete the necessary planning on their own. In the given context of this study, the PD sessions were compulsory and the teachers were required to implement STEM PBL lessons at least once every six weeks. An additional component was announcing when observations would take place. Therefore, the researchers had difficulty in determining to what extent the observed classrooms represented daily classroom instructional routines. Due to the administrational constraints, unannounced observations were not possible, which might limit the generalization of the results of this study to other cases.

Additionally, some teachers showed misunderstandings regarding STEM PBL, which might have been learned from the provided PD. For example, the participating teachers showed less control over their students and sometimes sat by and just watched students' performances. These behaviors came from the belief that STEM PBL should be student-centered. Moreover, the interdisciplinary feature of STEM PBL caused teachers to focus more on other disciplines without including rigorous mathematics content.

To persuade teachers to change their instructional approaches and to maintain the correct contentions on STEM PBL, sustained PD followed by feedback is necessary. The more sustained PD is, the more teachers learn from PD (Capraro et al., 2014; Garet et al., 2001; Joyce & Showers, 2002). Two teachers in the study, Linda and Susan, who had more than 20-years of teaching experience and more than three-years of STEM PBL PD experience, were more positive enacting STEM PBL activities than the other teachers in the study. As the teachers were involved in PD, they could be ready for the implementation of STEM PBL.

Teachers' Challenges in Implementing STEM PBLs

This study also illustrated teachers' challenges in implementing STEM PBL in the secondary schools. STEM PBL is a fairly new instructional pedagogy and teachers had a variety of challenges in implementation, even though PDs, seminars, and conferences on STEM PBL were provided for these teachers. The teachers' challenges in implementing STEM PBLs were related to diverse factors such as student's readiness, subject, technology, and time schedules, which were consistent with previous literatures (Ozel, 2013; Ward & Lee, 2002).

The participating teachers indicated student readiness was a critical factor in implementing STEM PBL. That is, teachers had difficulties in effectively implementing STEM PBL with students who were not academically ready. Students in the three participating schools demonstrated low academic achievement in mathematics on standardized state tests and were of lower economic status than those in other areas of the same region. Based on previous research, STEM PBL was more effective in learning environments with low achievers (Han, Capraro, & Capraro, 2014). However, implementation of STEM PBL with low achievers exhibiting behavioral issues was not easy for the teacher participants in this study. The teachers believed that the low achieving students' lack of familiarity with a student-driven learning environment would be another challenge in STEM PBL implementation.

Teachers desired extra time and effort for preparing to implement STEM PBL in their classrooms. Teachers needed more time to collaborate with other subject area teachers, order materials for STEM PBL activities, and design lesson plans. These were time- consuming tasks, and teachers are generally faced with many time limitations (Ozel, 2013; Ward & Lee, 2002). However, as materials and resources for STEM PBLs were accumulated, teachers were able to prepare for STEM PBL lessons more effectively and efficiently. These needs indicate that sustained continuous PD for at least one or two years was necessary to encourage teachers to enact STEM PBL activities continuously to facilitate having time to accumulate resources.

Teachers were often frustrated with small issues. Robert had difficulties related to computer software and students in his class not being able to access technology for their presentations. John displayed frustration when teachers from science, mathematics, and other subject areas were simultaneously implementing the STEM PBLs. He thought his students could not show their best performance in exploring STEM PBLs, because they were working on several projects at the same time. That is, John was frustrated with the schedules forced onto his colleagues and himself by administrators and PD providers. As indicated by McLeskey (2011) and Desimone, (2009), the mandatory aspect of the PD in this study lowered the teachers' and students' morale in implementing STEM PBL.

CONCLUSION AND IMPLICATION

This qualitative study examined the effect of STEM PBL PD sessions. In this study, the sustained PD was conducted to improve teachers' understanding of PBL. The findings described the individual teachers' understanding and implementation of STEM PBLs and compared these findings across the case study. The findings of this study may be used to ensure the fact that teachers' understanding cannot guarantee the quality of implementation of STEM PBL. Even though our five teachers learned the basic knowledge about STEM PBL and developed new conceptions about the implementation of it, their understandings differed from their classroom enactments of PBLs. Teachers may not fully comprehend new instructional reform methodologies and implement them differently than expected because of their alternate understandings or beliefs about these methods and their perceived importance with students in their classrooms. Students' content achievement, beliefs, self-efficacy, and motivation can be negatively influenced if teachers poorly implement PBLs. This present study may help to inform future efforts to enhance the quality of STEM PBL education for both teachers and their students.

To sum up, the findings of this study imply that more teacher-driven PDs should be designed to decrease the gap between the knowing and doing of STEM PBL. In addition, unannounced observations are suggested to evaluate if PD affects teachers' daily classroom instructional routines. Finally, a further study creating an instrument to measure students' readiness would assist teachers in better understanding their students and preparation for effective STEM PBL classroom instruction.

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APPENDIX

RUBRIC FOR LESSON PLAN EVALUATION

	5	4	3	2	1	0
1. Objectives (Selected from TEKS)	**Three or more** TEKS objectives all closely aligned with the PBL activities.	**Three or more** TEKS objectives and not more than 1 of them are tangential to the PBL activities.	**Two** or less TEKS objectives all closely aligned with the PBL activities.	**Two** or less TEKS objectives and one of them are tangential to the PBL activities.	No evidence	N/A
2. Connections: How does this PBL connect to other units in your subject?	The suggested STEM PBL is connected to **4 or more** interdisciplinary units from other subjects and **highly** related to each other.	The suggested STEM PBL is connected to **4 or more** interdisciplinary units from other subjects and is **not highly** related to each other.	The suggested STEM PBL is connected to **1~3** interdisciplinary units from other subjects and **highly** related to each other.	The suggested STEM PBL is connected to **1~3** units that are not interdisciplinary.	No evidence	N/A
3. Introduction: An introductory paragraph to the PBL written for the students	An introduction provides specific situations and environments that are **highly** related to students' lives.	An introduction provides specific situations and environments that **are highly** related to students' lives, but not a broad interest.	An introduction provides specific situations and environments that are **highly** related to students' lives, but not aligned to students' interests.	An introduction provides specific situations and environments that are **not related to students' lives**.	No evidence	N/A
4. Well-defined Outcome	Well-defined outcome clearly describes **exactly one** final product clearly using **appropriate key verbs** with necessary and sufficient constraints.	Well-defined outcome clearly describes **multiple and competing** final products clearly using **appropriate key verbs** with necessary and sufficient constraints.	Well-defined outcome clearly describes **exactly one** final product clearly using **non-specific verbs** with necessary and sufficient constraints.	Well-defined outcome clearly describes **multiple and competing** final products clearly using **non-specific verbs without** necessary and sufficient constraints.	No evidence	N/A
5. Materials used	All **five** kinds (Web, print, didactic, discourse, and kinetic materials) of materials are listed.	**Four of five** materials (Web, print, didactic, discourse, and kinetic materials) are listed.	**Three of five** materials (Web, print, didactic, discourse, and kinetic materials) are listed.	**Two or less** materials (Web, print, didactic, discourse, and kinetic materials) are listed.	No evidence	N/A
	5	4	3	2	1	0
6. Engagement	Engagement includes **four or more** tools that stimulate brainstorming, capture students' interests or outlines requirements, constraints, and durations (deadlines).	Engagement includes **three** tools that stimulate brainstorming, capture students' interests or outlines requirements, constraints, and durations (deadlines).	Engagement includes **two** tools that stimulate brainstorming, capture students' interests or outlines requirements, constraints, and durations (deadlines).	Engagement includes **one** tool that stimulates brainstorming; capture students' interests or outlines requirements, constraints, and durations (deadlines).	No evidence	N/A

7. Exploration	Exploration contains guiding questions, hands-on activities, ample opportunities to seek information from texts, online resources, and other experts, and general descriptions of students' tasks.	Exploration contains guiding questions including **at least two** of the following three components (1. Hands-on activities, 2. Opportunities to seek information, 3. Descriptions of students' tasks).	Exploration contains **two of the following four** components (1. Hands-on activities, 2. Opportunities to seek information, 3. Descriptions of students' tasks 4. Guiding questions).	Exploration **contains one of the following four** components (1. Hands-on activities, 2. Opportunities to seek information, 3. Descriptions of students' tasks 4. Guiding questions).	No evidence	N/A
8. Explanation	Explanation builds **necessary** contents knowledge to complete the STEM PBL.	Explanation builds necessary content knowledge to complete the STEM PBL; but is **limited on some specific content** knowledge.	Explanation focuses on **only one objective**.	Explanation focuses on **step-by-step procedure**.	No evidence	N/A
9. Extension	Extension is **highly** related to **main** objectives.	Extension is **highly** related to **other** objectives.	Extension is **partially** related to **main** objectives.	Extension is **partially** related to **other** objectives.	No evidence	N/A
10. Evaluation	Evaluation includes **authentic formative and summative** assessments with the rubric having **four or more indicators**.	Evaluation includes **either authentic formative or summative** assessments with the rubric having **at least three indicators.**	Evaluation includes **only summative** assessments with the rubric having **two indicators.**	Evaluation includes **only summative** assessments with **multiple-choice questions.**	No evidence	N/A