THE IMPACT OF STEM PBL TEACHER PROFESSIONAL DEVELOPMENT ON

STUDENT MATHEMATICS ACHIEVEMENT IN HIGH SCHOOLS

A Dissertation

by

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ABSTRACT

This dissertation consists of three articles that explore the effect of professional development (PD) on teachers' understanding and implementation of Science, Technology, Engineering, and Mathematics (STEM) project based learning (PBL), and the effect of STEM PBL on students' mathematics achievement. Teachers in three high schools participated in the research activities. They attended sustained PDs provided by one STEM center based in a Southwestern university, and were required to implement STEM PBLs once every six-weeks for three years (2008 through 2010).

The first article employed a mixed-method case study to explore the relation between the quality of the teachers' in-class STEM PBL implementations, understanding of the PBL in STEM education, and attendance in the STEM PBL activities. Quantitative findings indicate that attendance in the PD activities was significantly correlated with the quality of the in-class PBL implementation in 2010, yet not in 2011. Moreover, qualitative findings show that the teachers viewed the STEM PBL pedagogy as a means to promote student interest in mathematics, cultivate the interdisciplinary research culture in K-12 classrooms, and help improve students' content understanding.

The second article investigated the effect of STEM PBL, especially on Hispanic and at-risk students' mathematics achievement. The participants were 528 students in the three STEM PBL high schools and 2,688 students in non-STEM PBL schools in the same region. Latent growth modeling was used to analyze the repeated measures across

years. STEM PBL instruction positively influenced Hispanic students' achievement in mathematics, but not at-risk students.

The third study investigated whether participating in STEM PBL activities affected students who had varied performance levels, and to what extent students' individual factors influenced their mathematics achievement. The participants were 836 high school students in the three schools. The findings from the hierarchical linear modeling showed that low performing students showed statistically significantly higher growth rates on mathematics scores than high and middle performing students, over the three years. In addition, student's ethnicity and economic status were good predictors of academic achievement.

This dissertation is the first to reveal the effect of STEM PBL on student academic achievement relating to inservice teacher PD by employing the sophisticated research methodology.

DEDICATION

To my parents,

Han, Chul Hee and Lee, Myung Sook,

who made all of this possible,

for their endless patience, encouragement, and love.

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NOMENCLATURE

STEM	Science, Technology, Engineering, and Mathematics
PBL	Project Based Learning
PD	Professional Development
TAKS	Texas Assessment of Knowledge and Skills
TEKS	Texas Essential Knowledge and Skills

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Teachers and students have been faced with a crucial reason to implement science, technology, engineering, and mathematics (STEM) education in schools. First of all, STEM is a critical with national prominence. However, students have been avoiding STEM classes, and minority groups have been underrepresented in STEM majors and professions in the U.S. To satisfy the social needs of STEM fields, the U.S. Department of Education and the National Science Foundation have funded STEM education for K-12 students. STEM subjects can be learned more effectively while being integrated with each other (Dugger, 1993). In addition, project based learning (PBL) has been regarded as an appropriate approach to increase the synergistic effect of STEM learning (Capraro & Slough, 2008). However, the reality of STEM education in schools, especially the effect of STEM PBL on student academic achievement, has not been researched sufficiently. Therefore, I investigated how teachers understand and implement STEM PBLs, and to what extent students improve their academic achievement through STEM PBL activities.

Literature Review

STEM PBL

STEM PBL is an interdisciplinary instructional approach utilizing a project. STEM PBL was defined as ―a well-defined outcome with an ill-defined task" (Capraro & Slough, 2008, p. 2). STEM PBL is an interdisciplinary teaching and learning approach

leading students to explore ill-defined problems across subjects within a constrained environment. An interdisciplinary approach, hands-on activities, collaboration, team communication, knowledge construction, and formative assessment have been indicated as primary components of STEM PBL (Barron et al., 1998; Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt [CTGV], 1999; Slough & Milam, 2008; Thomas, 2000). As STEM literally stands for four subjects, STEM PBL combines disciplines from science, technology, engineering, and mathematics (Capraro, 2008; Lou, Liu, Shih, Chuang, & Tseng, 2011). In STEM PBL, students apply abstract concepts of science and mathematics to an engineering context using technology tools (Morgan, Moon, & Barroso, 2008). Students have the opportunity to communicate and collaborate with peers and teachers in small groups while exploring a project (Chen, Lam, & Chan, 2008). These opportunities stimulate students to construct their own knowledge and make use of formative feedback that is important in the STEM PBL lessons (Capraro & Yetkiner, 2008).

STEM PBL has been developed from a well-known instructional method based on engineering principles to improve students' problem solving skills, deep understanding of content, and communication skills. For example, STEM PBL engages students in solving problems within a project individually and in groups while they explore strategies and apply content knowledge to real-world tasks (Barron et al., 1998). Through a project composed of several problems, students can apply their knowledge learned before or at present to finding strategies to solve new problems or new contexts, recognize their meaning in their lives, and gain a deep understanding of the subjects

(Goldman et al., 1999). Moreover, because STEM PBL consists of diverse hands-on activities, communication, and collaboration with peers, it helps students develop positive attitudes and reduce anxiety about science and mathematics (Blumenfeld, Fishman, Krajcik, Marx & Soloway, 2000).

<div align="center">*Professional Development for Teachers*</div>

A teacher's own mathematical and pedagogical content knowledge has a substantial impact on students' gains (Hill, Rowan, & Ball, 2005). This is one of the critical reasons to provide teachers with sustained professional development (PD) (Capraro et al., 2012). Practically, PDs have affected teachers in diverse phases (Guskey, 2003). Many studies have reported that PDs implementing STEM PBL were successful for increasing teachers' self-efficacy and improvement of classroom practices (Hmelo-Silver, 2004; Shin et al., 2010). After PD completion, teachers reported that they could use more standards-based teaching practices, informal assessment, and communication and technological instruments than they did prior. Furthermore, the employed strategies (i.e., questioning, re-voicing, making connections, clarifying, reframing, summarizing, role playing, meta-talk, and modeling) in the PD improved the teachers' collaboration skill in the science community (Zhang, Lundeberg, & Eberhardt, 2011). As well as the pedagogical content knowledge, PD positively influenced teachers' content knowledge. For example, a two-year long PD activity impacted the teachers' content knowledge and teaching knowledge of rational number topics (Garet et al., 2011). Teachers' knowledge slightly increased at the end of the second year of implementation.

However, PD was not always effective. Based on the quantitative results from Roesken's (2011) study, teachers had difficulty implementing what they learned from PD in their teaching practices. They gave up on the new ideas and suggestions and went back to the traditional methods because the content was not sufficiently related to their practice. The suggestions obtained through the inservice training course proved to be impractical afterwards.

Teachers sometimes see the PD as separate from their classroom practices. In other words, teachers who participated in PD did not apply what they were taught in their classrooms either because of classroom situations and/or school climate were different from the models introduced in the PD or because teachers lacked enthusiasm to adopt instructional reform models (Roesken, 2011). In addition, some PDs were implemented top-down, from the policy makers (i.e., administrators, university level educators and national education departments) perspectives to the teachers' contexts (Kent, 2004). Hence, some teachers were left behind on the issues associated with the PD.

Effect of STEM PBL

The effect of STEM PBL on student academic achievement has been debated. Previous studies did not always report the positive effects of STEM PBL on students' achievement. Most studies verified the effectiveness of STEM PBL (Collins, Hawkins, & Carver, 1991; Goldman et al., 1999; Hmelo-Silver, 2004; Schauble, Glaser, Duschl, Schulze, & John, 1995). However, some researchers pointed out that STEM PBL may

not guarantee a positive effect by itself, but depends on the teachers' and students'

readiness for implementing it (Barron et al., 1998; Capraro et al., 2012).

Each researcher has used varied meanings for the term ─effective," and the

methods to measure the effect have been different in studies of STEM PBL. For

example, McCray, DeHaan, and Schuck (2003) assumed that effective STEM PBL led

students to achieve a positive learning outcome and mentioned that it should ─be able to

elicit and measure students' conceptual understanding and their ability to transfer

knowledge to new contexts" (p. 10). Lou et al. (2011) stated that the effectiveness of

STEM PBL could be examined by observing students' learning and the differences after

the students engaged in STEM BPL activities with the instruments, questionnaire and

interview. In the study by Kaldi, Filippatou, and Govaris (2011), the effects of STEM

PBL were investigated in a quasi-experimental research design (i.e., pre-test-post-test

design) accompanied by a qualitative analysis.

The effects of STEM PBL have been reported widely and broadly. Students who

experienced STEM PBL showed a positive attitude toward learning, team

communication, and collaborative behavior (Domínguez & Jaime, 2010; Johnson et al.,

1998; Kaldi et al, 2011; van Rooij, 2009; Veenman, Kenter, & Post, 2000). Other

reported effects of STEM PBL were to increase students' interest, self-confidence and

self-efficacy (Baran & Maskan, 2010). The positive impact of STEM PBL on students'

attitudes was highly related to the cooperative studies and contextual problems of the

real world. In addition, students who studied in STEM PBL classrooms were less likely

to drop out of courses and school (Domínguez & Jaime, 2010). Several studies have

supported the positive impact of STEM PBL on student's content knowledge (Boaler, 1997; Barron et al., 1998; Liu & Hsiao, 2002). Hands-on activities and field-based contexts of STEM PBL were the primary factors that resulted in positive effects on students' content knowledge (Kaldi et al., 2011). Moreover, the interdisciplinary learning environment positively influenced students' scores, quality of outcomes, and team interactions, which were examined by comparing experimental and control groups (van Rooij, 2009). The result in terms of outcome quality was not significant, even though the mean score of the test group was a little higher and students' team interactions were stimulated during the 8-week project lifecycle.

Most studies that examined the effectiveness of STEM PBL obtained positive effect sizes and statistically significant differences ($p < .05$) (Baran & Maskan, 2010). Secondary level students longitudinally showed positive growth rates of academic achievement while being engaged in STEM PBLs (Capraro et al., 2012). In the university level, students, to whom the STEM PBL approach was applied, obtained higher scores than those to whom the traditional method was applied (Baran & Maskan, 2010). One interesting fact from Baran and Maskan (2010)'s study was that students' scores were statistically different in the comprehension step, but not in the knowledge and application steps.

Student individual and environmental factors affect their academic achievement (Capraro, 2001; Capraro et al., 2012; Konstantopoulos, 2009; Shores, Shannon, & Smith, 2010;). Student individual factors indicate variables depending on personal demographics, characteristics, attitudes, and abilities. For example, gender,

race/ethnicity, SES, language proficiency, and educational risk have been regarded as individual factors. On the other hand, environmental factors indicate variables depending on school and classroom climate, teacher quality, instructional approach, and curricula system. STEM PBL is one of environmental factors resulting in changes in classroom climate, teacher's quality, and instructional approach.

The effects of STEM PBL were different depending on individual student factors. In addition to the learning environment factor, STEM PBL, student achievement was influenced by individual factors (Konstantopoulos, 2009; Lubienski, 2002; Ma & Klinger, 2000; Shores et al., 2010; Tate, 1997). Most studies consistently showed that SES was a critical predictor of mathematics achievement. However, the influence of ethnicity on student academic achievement was varied in the previous studies (Capraro, 2001; Ma & Klinger, 2000). The gender effect on students' scores also appeared diverse depending on student individual factors or different subjects (i.e., mathematics, science, reading, and writing) (Konstantopoulos, 2009; Ma & Klinger, 2000; Shores et al., 2010). Therefore, this dissertation was designed to investigate how the effect of STEM PBL depends on student diverse factors.

Overview of the Dissertation

In this dissertation, I mainly demonstrated the effect of STEM PBL on student academic achievement by improving teacher's instructional approach (see Figure 1). The intervention program includes the sustained PD, professional learning communities, and partnership between teachers and content specialists. Students' mathematics

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achievement was the main outcome. The final goal of teacher PD is to improve student's academic achievement as well as to refine teacher's pedagogical knowledge.
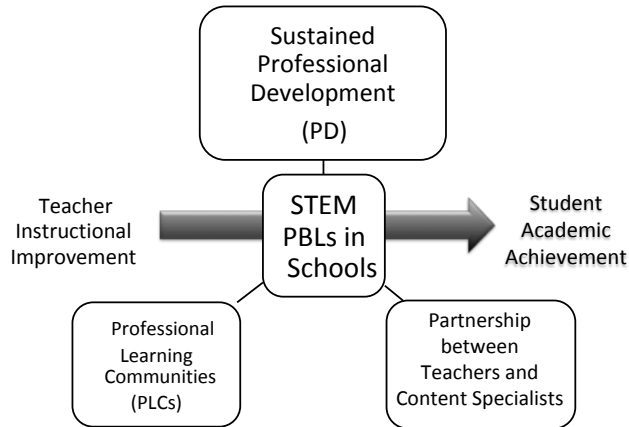
Figure 1. Intervention program.

The idea on the evaluation of STEM PBL PD was elaborated with three research questions relating to improvement in teacher's perceptions and implementation, and student's academic achievement.

1. What is the retention of the PDs on the teachers' STEM PBL implementation in class? What are the participating mathematics and science teachers' understanding of and beliefs towards STEM PBL and how do they implement it in their classrooms (enactment)?

2. Is STEM PBL effective for Hispanic students in terms of their growth rate in mathematics scores across the three years? Is STEM PBL effective for at-risk students in general in terms of mathematics scores across the three years? Among

at-risk students, is STEM PBL as effective for Hispanic and non-Hispanic students in terms of growth rate in mathematics scores across the three years?

3. How does STEM PBL differently affect students who have varied proficiency levels (i.e., high, middle, and low)? To what extent do students' factors (i.e., gender, ethnicity, economic disability, limited English proficiency (LEP), English as a second language (ESL), special education, gifted, and at risk) influence mathematics achievement accompanied by the proficiency impact?

In the three articles of this dissertation, I investigated how students and teachers have been changed in terms of their performance by implementing STEM PBL lessons in their classrooms. One article reported teachers' individual perceptions and implementations of STEM PBL using qualitative and quantitative data (i.e., lesson plans, observation forms, and interview transcriptions) and two articles examined the effectiveness of STEM PBL on students' achievement using quantitative data (i.e., state standardized test scores). The purpose of the first article was primarily to describe teachers' actual perceptions and implementation of STEM PBL in their classrooms after participating in the PD. The second article focused on the comparison of student scores between two groups (i.e., STEM PBL schools vs. non-STEM PBL schools). Specifically, the effect of STEM PBL on Hispanic and at-risk students was verified. Last, the third article verified the changes in students' mathematics scores on state standardized tests after participating in STEM PBL lessons. Specifically, it proved that STEM PBL provided different impacts on students who have varied proficiency levels. Thus, these three articles contributed to an important area of research in the STEM education field.

In addition, this dissertation shows that evaluation of PD in terms of students' improvement in academic achievement represents teachers' effective instruction.

For each article, two potential journals have been selected for publication of the manuscript in three steps. First of all, I selected journals which include articles cited in the literature review of this dissertation. Secondly, the scope and expected reader described in the web page of each journal was considered for aptness. The third step was searching the impact factor and considering the prestige of the editorial board. Impact factors or *SCImago Journal Rank* (SJR) and *Source Normalized Impact per Paper* (SNIP) were found on the primary web sites; *Scopus database of abstracts and citations for scholarly journal articles* and *Journal Citation Reports Social Sciences Citation Index* (JCR-SSCI). Acceptance rates, review type, and length of manuscript from *Cabell's Directories* were referenced to choose the journals (see Appendix A).

The methodological approach of the three articles in this dissertation was different according to the research question of each study and type of collected data. Quantitative statistical analysis was used in the second and third article whereas the first article employed a mixed method research design. The first article utilized a mixed method including binary regression model and case study. In the second and third article, rigorous quantitative analysis approaches (i.e., structure equation model and hierarchical linear model (HLM)) were utilized to decrease error variances. In addition, effect sizes (e.g., Hedge's g, 2 restricted log likelihood (2LL), or explained variances) were reported for practical significance.

CHAPTER II

IN-SERVICE TEACHERS' IMPLEMENTATION AND UNDERSTANDING OF PBL

IN STEM FIELDS

The role of PBL in STEM education has gained interest since the beginning of the 21st century (Thomas, 2000). A STEM PBL instruction is quite different from a knowledge-centered, traditional instruction, and it requires the teacher to fully comprehend its pedagogical orientation for a successful teaching practice. Effective PD can help teachers acquire the pedagogical orientation of STEM PBL (Capraro et al., 2012). Teachers' understanding and implementation of STEM PBL play a major role in students' STEM PBL experiences. Students learned more from skilled and experienced teachers with STEM PBL, whereas teachers who ineffectively implement PBL instruction had a negative effect on students' performance (Capraro et al., 2012). In-service teachers should be informed about the pedagogical orientation of the PBL and be guided to design and implement STEM PBL activities preferably through PDs (Capraro et al., 2012).

The purposes of this study were to examine the effects of PDs and explore the teachers' understanding and implementation of STEM PBL activities using a mixed-methods research approach. Exploring teachers' understanding and implementation of STEM PBL activities was necessary to evaluate the PDs given to the teachers and to improve the quality of students' STEM PBL experiences in classrooms.

Literature Review

Defining STEM PBL

Two central traces define the PBL in the literature; (a) Kilpatrick (1918)'s

project method, and (b) the reform movement in early 21st century. The STEM PBL we

refer to in this paper is within the boundary of the later one. The progressive education

reform movement in 21st century was more willing to apply the PBL in K-12 education,

whereas the PBL pedagogy before the 21st century was mostly implemented in the

postsecondary education and in the medical and engineering fields (Steipen & Gallagher,

1993). PBL might be defined more clearly by comparing it with problem based learning.

PBL focused on five components: ―centrality, driving question, constructive

investigations, autonomy, and realism‖ (Thomas, 2000, p. 4). 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

handed to them (Slough & Milam, 2008).

STEM PBL has been defined as ―a well-defined outcome with an ill-defined

task‖ (Capraro & Slough, 2008, p. 2) and used as a student-centered instructional

method (Bransford, Brown, & Cocking, 1999). STEM PBL not only is a word to

indicate an instructional approach using a project in the four subject areas, but also

includes teaching orientation grounded on constructivism and constructionism (Woods

& Morgan, 2008). A STEM PBL activity is interdisciplinary in nature and requires

students to locate and define a problem as they explore a project topic (Capraro, 2008).

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 in STEM PBLs (Ozel, 2008). Students have opportunities to construct their own knowledge with deep understanding on disciplines in STEM PBLs, whereas teachers disseminate the content knowledge in traditional classrooms (Ozel, 2008). The goal of STEM PBL was 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 is 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 at a school. Teachers can improve the quality of their instruction as they gain more experience in teaching only if they are willing to self-reflect on their teaching practices and use their metacognitive skills as they iterate their instructional design. Nevertheless, few teachers were willing to change or modify the design of their instructions (Guskey, 2003). Hence, some mandatory PDs have been recommended.

The teachers' role in STEM PBL has to be different from one in the traditional classrooms and should be changed to adapting to new principles of the 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). To implement a new pedagogical orientation such as STEM PBL, teachers were expected to have: fulfilled

self-efficacy, a skill to see a big picture, a metacognitive skill, and an ability to organize professional learning community (Caine & Caine, 1997).

Teachers' understanding and implementation of the STEM PBL greatly affected the students' content understanding and developing skills (Capraro et al., 2012). Without doubt, students learned more from the teachers who were qualified with profound content and pedagogical knowledge (Darling-Hammond, 2000; Darling-Hammond & Youngs, 2002; Goldhaber, 2002; Rice, 2003; Wayne & Youngs, 2003). Even in the STEM PBL classroom environment, 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 (Capraro et al., 2012). Students, who were given the lower quality of STEM PBL lessons, showed negative growth rate (Capraro et al., 2012). Hence, effective PDs are of importance for the teachers who will implement STEM PBL in their classrooms.

Characteristics of an effective PD and its components have been discussed for a long time. Many researchers investigated the effectiveness of PDs by comparing teachers and students' performances before and after the PD interventions (Garet et al., 2011). The sustainability and intensity were identified as critical features of an effective PD (Capraro et al., 2012; Garet et al., 2001; Joyce & Showers, 2002). Sustained PDs in 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 community (Erickson, Brandes, Mitchell, & Mitchell, 2005; van

Es, 2011) were reported effective to enhance teachers' skills and knowledge. However, it was 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 lot of funding has been invested in PDs for in-service and pre-service teachers, the teachers' practices in the real classrooms have not been changed as much as expected (McLeskey, 2009). An expert-centered PD, compared to a learner-centered PD, rarely enabled the changes in teaching practices to be realized (McLeskey, 2009). The expert-centered setting indicated a PD that was provided by an outside specialist, who was well known with reformed education (Choy, Chen, & Bugarin, 2006), and teachers were given knowledge on the innovative instructional approaches passively. On the contrary, the learner-centered PD engaged the teachers in the PD activities more actively to promote deep understanding on the innovative practice (Desimone, 2009; McLeskey, 2009). 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 to change teachers' actual instructional approaches than the learner-centered PD (McLeskey, 2009). Therefore, the effectiveness of a PD should be evaluated based on the PD's impact on an actual in-class teaching setting.

As teachers were required to change their teaching practices to adapt to an educational reform movement, they encountered different challenges (Ward & Lee, 2002). In a STEM PBL classroom setting, teachers were expected to exhibit skills and

abilities that they were not used to in a traditional classroom setting. First, teachers

needed to share controls with students for classroom management in STEM BPL (Ozel,

2008; 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 the

students continue their works. Teachers had more difficulties in implementing STEM

PBLs if they were primarily used to implementing traditional instructional approach

(Ozel, 2008). 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 have different teaching areas,

timetables, and teaching philosophies. They needed to spend extra time and effort to

prepare for a STEM PBL classroom. Last, teachers had difficulties adapting the

characteristics of STEM PBL they have learned in the PDs to their in-class teaching

(Ward & Lee, 2002). A top down approach has been used in offering PDs. In other

words, university faculty or governmental agencies usually delivered the PDs to the

teachers. Teachers had additional barriers to even try the STEM PBL instructions in their

classroom because they barely gained any sufficient practical experience out of a PD

(Ward & Lee, 2002). An effective PD should provide sufficient practical experience in

STEM PBL.

Research Questions

The quantitative and qualitative data collected were analyzed to draw several themes (Creswell, 2007; Denzin & Lincoln, 2005) and used to answer the following research questions:

1. What is the retention of the PDs on the teachers' STEM PBL implementation in class?

2. What are the participating mathematics and science teachers' understanding of and beliefs towards STEM PBL and how do they implement it in their classrooms (enactment)?

Methods

Participants

One hundred seven teachers participated in the research activities from 2006 to 2010. Thirty-five teachers' in class STEM PBL implementation methods attended PDs and were observed in 2010 and 32 teachers in 2011. The participants were recruited from three schools – one charter school and two STEM academies. Teachers attended 10 PD sessions in a year. A team of researchers and faculty at a STEM center that was funded by a state wide project provided the PD sessions. Student population in the three schools was mostly Hispanic and African American, and it was categorized as economically disadvantaged (i.e., students who were eligible for free and reduced-price meals) and at-risk (Texas Education Agency [TEA], 2011). The overarching goal of the STEM center was to improve the students' readiness for their postsecondary education with particular emphasis on the economically disadvantaged and low-performance

students in the STEM fields. The teachers' attendance in the PD sessions was mandatory. Teachers were informed about the design principles of STEM PBL classes and asked to prepare 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 year.

To answer the second research question, five in-service mathematics and science teachers (pseudonyms: Linda, Robert, John, Chira, and Susan) in an urban school district in Texas were randomly assigned to the first author to be observed. We employed a case study with the five teachers. All five teachers participated in PD activities on STEM PBL. A team of researchers at the STEM centre observed the teachers' STEM PBL enactment and conducted individual interviews. Two (i.e., Robert and John) of them were male and White. The other three were female, two (i.e., Linda and Susan) of whom 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).

Table 1

Teachers' demographic information

Participant Name	Sex	Ethnicity/Race	Subjects taught at the time of data collection
Linda	Female	White	Environmental systems
Robert	Male	White	Precalculus
John	Male	White	Algebra
Chira	Female	Asian-American	Algebra
Susan	Female	White	Geometry

Data Collection

In this study, we collected both quantitative and qualitative data to answer the research questions. For the quantitative analysis, teachers' attendance in the PD session between the years 2008 and 2010 and their in class STEM PBLs observation scores captured by two different observation protocols in two different years (2012 and 2011) were collected. Stearns, Morgan, Capraro and Capraro (2012) developed the original observation protocol (27 items) in 2011 and we used the revised one (22 items) in 2012. A group of researchers had received trainings on how to use the observation protocols prior to their data collection. The items of the observation protocols were rated on a five point Likert-scale (i.e., 1 to 5) and N/A. The score, 5 means ―to a great extent,‖ 1 means ―no evidence,‖ and N/A is ―not applicable.‖ Each participant's scores from the observation instruments were summed up and the composite scores were used in the analysis process.

The three protocols used to collect qualitative data were (a) each participant's lesson plan protocol, (b) an in-class participant observation protocol, and (c) one-on-one semi-structured interview protocol. The teachers designed their lesson plans prior to their in class implementation and shared them with the content experts at the STEM center. We analyzed the lesson plans and characterized the pedagogical orientation embedded in the lesson design. A sample lesson plan and its analysis rubric were presented in the Appendix B and C. Each class observation lasted 50 minutes and an evaluation instrument was completed during the observation. The observer asked the students in class several questions and recorded the responses to further analyze and

verify them with the teachers' implementation of STEM PBL. Five of the teachers who participated in this study were invited for individual interviews. All agreed to participate. In the interviews, we asked questions to the teachers about their experiences in teaching with the STEM PBL. Each interview took around 30 minutes. We audio-recorded the interviews on an I-Pad. 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 initiate a conversation about the participants' STEM PBL instruction in their classrooms to capture the participants' understanding from and implementation of STEM PBL. The fourth question helped triangulate the participants' understanding of the purpose of STEM PBL instruction.

Data Analysis

This study employed a mixed-method approach and utilized various types of data. A mixed-method approach was more appropriate in the present study to provide both rich information on the case and evidence for generalization (Creswell, 2007). To answer the first and second research questions, descriptive statistics (i.e., mean, standard

deviation, and correlation coefficient) and bivariate regression were utilized. The employed bivariate regression enabled to identify the extent to which the predictor variable contribute unique variance to predicting teacher's scores in enacting STEM PLBs. The bivariate regression model was utilized to predict and explain the dependent variable, teacher's observation score, by the independent variable, the total hours attending to PDs from 2008 to 2010. For the third research question, a case study was conducted to explore the teachers' lived experiences with the PD activities and their in-class implementations of STEM PBL (Denzin & Lincoln, 2005; Yin, 2003). The design was a collective case study with multiple cases (Stake, 2005) augmented with a descriptive case study design (Yin, 2003). Each teacher represented a single case and all five teachers were describing one common issue. This study aimed at capturing inservice teachers' understanding of STEM PBL and how they organize their classes accordingly. To describe and compare teachers' understanding from and implementation of STEM PBL, we conducted both within-case and cross-case analyses with the five teachers participated in the case study.

The case study was implemented by analyzing the teachers' lesson plans, observation descriptions, and interview transcriptions. We reviewed the teachers' lesson plans using a rubric for lesson plans developed by the two authors and we provided feedback to the teachers. Lesson plans signaled teachers' understandings of STEM PBL and their perception of STEM PBL implementation in class. We utilized the findings from the lesson plans when we compared 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 four steps. The first author transcribed the recorded conversations and an external peer has reviewed the transcriptions for accuracy. Next, we read the transcriptions several times and performed open, axial, and selective coding (Glaser & Strauss, 1967). Then we conducted within case and cross case analyses. In the within case analysis, each teacher and the data collected about her were analyzed independently. In cross case analysis, the five teachers and the findings generated in the within- case analyses were analyzed as a whole. Commonalities and differences between the teachers are reported in the cross-case analyses.

Findings

Quantitative Findings

The descriptive statistics showed that the teachers observed in 2010 reported different outcome scores than the teachers observed in 2011. The means of the observation scores for the 35 teachers observed in 2010 was 77.628 (SD=17.265) and for the 32 teachers observed in 2011 was 70.250 (SD=14.147). The teachers' attendance to the PDs significantly and positively correlated (r=0.371, p<0.05) with their observation scores in 2010. In 2011, the teachers' attendance to the PDs insignificantly and negatively correlated (r=-0.041, p>0.1) with their observation scores.

To determine whether the teachers' PD attendance was associated with their observation scores, the sum of the observation scores in 2010 and 2011 were regressed

on the total number of PD hours between 2008 and 2010. The result from the bivariate

regression of 2010 observation scores was statistically significant, $(F(1, 33)=5.274,$

$p<0.05, r^2=0.138)$, indicating that 13.8% of the variance of observation scores was

accounted for by how many hours teachers attended to PDs. The prediction equation is

as follow:

$$Observation\ score = 0.310 \times (Hours\ attend\ the\ PDs) + 16.08$$

However, the result of bivariate regression of 2011 observation scores was not

statistically significant, $(F(1, 30)=0.050, p>0.5)$, indicating that the teachers' PDs

attendance between 2008 and 2010 was not a good predictor of their observation scores

in 2011.

Case Study Findings

In this section, we first report the findings for each case (e.g., the teacher)

derived from the within-case analyses. Next we compare and contrast the individual

cases, that is, we report the findings from the cross-case analysis.

Case 1: Linda

Linda was eager to learn about the STEM PBL and to implement it in her classes.

She has attended the PDs since 2008 and received a better observation rating (s=71) than

the average in 2011 (70.250), but it was lower than average in 2010 (77.628). She had

been teaching different science subjects each year. 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 engaging students with their prior knowledge and culturally diverse contexts. She identified herself as an expert with the basic contents of STEM PBL and emphasized a deep understanding of STEM PBL for a better STEM PBL 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. Moreover, it was more difficult for her to prepare the STEM PBL lesson because the subject, environmental systems, is new, and different from other science subjects such as biology and chemistry in the sense that there has been very little accumulative information related to the environmental systems. That is, she considered that a preparation of STEM PBL is not a difficult task to teachers who are teaching subjects more familiar to them.

Linda believed that student‘s readiness for STEM PBL is critical in implementing it in classrooms, and said that ―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‘s students‘ individual reports were graded daily. Their poster presentations were their project outcome/artefact. In addition, the group presentation was a major grade for the group members. Students were assessed both individually and as a group. However, 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.

Her students were not as concerned as in the rubric and how teachers evaluated them,

than how much Linda expected. Because the rubric was associated with the teaching and

learning goal of STEM PBL, students' insufficient understanding on the rubric might

hinder Linda to implement the better STEM PBL.

Case 2: Robert

Robert was observed once in 2011, and received a rating (s=56) less than the

average observation score (70.250). Although Robert was still a novice in implementing

STEM PBL in his classroom, he had a quite strong belief how a STEM PBL should be.

He was certain that STEM PBL should reflect students' future as well as present lives.

Therefore, his STEM PBL lesson plan actually was associated with students' future

professions and income. However, he showed several enactments that did not match to

the designed lesson plan. Robert forgot passing the hand out and the project assessment

rubric to the students in class. In addition, he did not check the computer to make it 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. Critically, his STEM

PBL did not include rigorous mathematics content in the observed class, even though he

was teaching precalculus. He commented in class ―no math at all.‖ His understanding of

the interdisciplinary nature of the STEM PBL led to apply other subjects' contents into

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the mathematics class; but he missed teaching mathematics along with other subjects in his designed STEM PBL. However, the lesson plan included precalculus content, for example, log, sines, and cosines to figure out the area that students were going to choose in the second phase of the project. Robert did not assign his students into groups for the project, even though he has the indicator, ‗collaboration with peers' in the rubric. He preferred the students to work individually to estimate their future salaries, which was a part of well-defined outcome of the project.

Robert displayed low confidence in his students similar to Linda. 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 learning goals and criteria on the assessment rubric that are some critical components of the PBL instruction. This might be the reason why Robert gave students elementary instruction to follow easily. Nevertheless, students' self interests in the topic were very high and they completed the project with enthusiasm.

Case 3: John

John has attended PDs since 2008, and received a rating (s=94) better than the average observation score in 2010 (77.628) and a lower rating (s=67) in 2011 (70.250). Even though John was skeptical about the benefit of STEM PBL, he also strongly believed that teachers' participation in the STEM PBL classes should be minimum. He believed that STEM PBL is more likely to help students review what they learn, rather than to understand new concepts. This was why he picked the topic that students were being taught for one month and a half. He designed the lesson plan using STEM PBL for the review of the topic, and based on his first STEM PBL implementation in class. 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. He created the rubric only for evaluating the presentation on the last day. Even though John mentioned to the students that they were going to receive a grade for their work effort and behavior during the preparation in class, he did not prepare a rubric that either evaluated students' behavior or their contribution to the project.

John also had some challenges in implementing STEM PBL in his classroom. One challenge was the several project implementations in tandem without stressing the students. John reported that the miscommunication between teachers and PD providers was the cause of several project implementations at once. Because the PD observers, including the interviewer, could visit the schools only one day, this required the teachers in each subject to implement their STEM PBL lessons simultaneously. John believed that this affected student performances negatively and the time constraints hindered students to complete involvement with the project activities.

Case 4: Chira

Chira showed a lower observation score (s=67) compared to the average in 2011 (70.250), but received a higher (s=88) in 2010 (77.628). She has been involved in STEM PDs since 2008. She defined ―project based learning as interdisciplinary" and believed in the positive impacts of STEM PBL. Compared to John, Chira displayed different teaching behaviors, even though their basic ideology of a teachers' role in STEM PBL classes had some common qualities. Chira continually circulated to students' tables while answering students' questions but always observing what students were doing.

Chira believed that constant feedback during the STEM PBL class was effective for students' deep understanding of content; however, she pointed out that students were not always interested in the goals or tasks. She characterized her students in the STEM PBL class as ―When it's implemented, there is neither engagement nor student talk about the topic." For the formative assessment of STEM PBL, Chira continuously recorded students' work and their behaviours during the project 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 whether the presentations were mathematically correct, whether the presentations were related to quadratics, whether the content was creative, and whether the speaker had both a clear voice and eye contact with his/her audience.

Case 5: Susan

Susan was enthusiastic to attend PDs and to implement STEM PBLs. She had participated in PDs since 2008 and received higher observation ratings (123 and 76 in 2010 and 2011, respectively) than the average scores in 2010 (77.628) and 2011 (70.250). During the interview, Susan shared how eager she was to implement STEM PBLs in her classroom. Nevertheless, 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.

Susan thought student interest was critical for success in implementing STEM PBL. Basically, she assumed that current students were different than students in the past. In the past, students would solve problems using paper and pencil, whereas current students do not do that. Her current students need lots of motivation with diverse materials, not just with paper and pencil. 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, students were encouraged to take pictures outside the classroom. In the class that the researcher observed, all students were focusing in class and were eager to explore the problem of designing lessons for absent students.

Susan indicated that teacher roles in classrooms have changed due to student characteristics. As previously mentioned, 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. In addition, Susan described the passive role of teachers in STEM PBL classes.

Cross-Case Analysis 1: New Conceptions on STEM PBL Provided by PDs

Five teachers illustrated concepts on STEM PBL different from a traditional classroom. Teachers' STEM PBLs included more practical purposes, tasks covering diverse subjects, and fewer instructions than a traditional classroom. 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, he asked his students to estimate their future salaries and budget. On 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 with students' lives. All participants considered STEM PBL an interdisciplinary activity in nature. Their lesson plans included two or more subjects (e.g. art, technology, social studies), yet not all of them listed the learning objectives for diverse subjects. For example, Susan believed that a STEM PBL activity could help ESL students. She knew that artistic components could stimulate certain students' interests and thus used a video clip during the implementation of her STEM PBL. After implementing STEM PBLs in their classrooms, the teachers were asked about their role in STEM PBL classes based on their experiences. They felt that STEM PBL classes were basically organized differently from traditional classes and teachers were given particular expectations. John defined his role in STEM PBL classes as a ―guide‖ and 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 the one in traditional classes, because students, materials, and curriculum have changed even though content topics and objectives are similar.

Cross-Case Analysis 2: Teachers' Enactments of STEM PBL Different from Conceptions

Even though teachers generally believed in the positive effectiveness of STEM PBL, they still regarded STEM PBL as an obstacle to preparing summative tests. This indicated that teachers understood STEM PBL as distinct from the traditional curriculum. The findings of this research suggested that there was a contradiction between their perceived notions of the effectiveness of STEM PBL. In other words, teachers revealed their beliefs that STEM PBL might improve student understanding of content; but on the other hand, they tended not to expect student scores on summative tests to be higher after engaging in STEM PBL lessons.

The extent to which teachers actively participate in their students' project work was labeled as ―facilitation.‖ What our participants told us and what they actually enacted in their classrooms differed. Although Linda, Susan, and Chira assumed passive roles while implementing a PBL activity during the interview, they played active roles in their classroom enactments of their PBL. These teachers circulated to each team's table and consistently provided feedback on students' performance. On the contrary, Robert and John provided very few instructions and let their students explore the topics themselves.

STEM PBL lessons contained different student performance expectations as a result of the nature of the project. As an approach to include processes, trials, effort, and outcomes together, rubrics could guide teachers in assessing non-traditional outcomes objectively. Teachers basically created their own rubrics for their STEM PBL lessons;

but they approached rubrics differently. Linda, Chira, and Susan prepared holistic rubrics including various indicators for evaluating final outcomes (e.g. presentations or models) and procedures. Conversely, Robert and John used their rubrics for merely evaluating the final presentation. Linda and Chira were attempting to use rubrics to evaluate students daily as an assessment, whereas Robert, John, and Susan were more likely to use the rubric only for the final presentation. In case of Susan, she did not formatively assess trials while evaluating students' working and behavior each day even though she designed the rubric with relatively diverse indicators.

Cross-Case Analysis 3: Teachers' Challenges in Implementing STEM PBLs

STEM PBL was a fairly new instructional pedagogy and teachers had many challenges in implementation, even though PDs, seminars, and conferences on STEM PBL have been provided for teachers. Teachers were often frustrated with small issues. Robert had difficulties related to computer software and students in his class could not access technology for their presentations. Chira was trying to assign students into different groups for every project and this wasted instructional time during her STEM PBL lessons. Robert and John displayed frustration when science, mathematics, and some other subject areas were implemented simultaneously with the STEM PBLs. Robert and John thought students could not show the best performance in exploring STEM PBLs, because they needed to do several projects at the same time. That is, Robert and John frustrated with the schedules forced to them by administrators and PD providers.

Discussion

A teacher is a critical factor for implementing any education reform including STEM PBL as well as for students' positive improvements. However, there are very few studies that investigated what teachers learned from PDs on STEM PBL and how they practically adapted to their classrooms. To develop a more effective PD in practice, it is crucial to look at the relationship between the sustained PDs and the sustainability of PD's impacts, because this indicates the effect of PDs. Moreover, it is important to illuminate the relationship between teachers' understanding and implementation of STEM PBL, because what teachers implement in their classrooms may be different from what they learn from the PDs. The ultimate goal of PDs is to lead teachers to utilize their learning from PDs in their classrooms in an appropriate way. In this sense, educators need to investigate how well teachers adopted education reform into their lessons, not only to provide PDs. This study contributes to see impacts of PDs on teachers' instructional conceptions and practices of STEM PBL with the mixed method approach.

The results of the present study support that sustainability of PD is the critical component to maximize teachers' improvement in implementing education reform. Yoon, Duncan, Lee, Scarloss, and Shapley (2007) examined that ample time (i.e., 30 to 100 contact hours) over 6 to 12 months was necessary for the high quality of PDs. The regularity of PD was pointed out as a crucial factor of the effective PD (Garet et al., 2001). In addition, Capraro et al. (2012) investigated that the sustained PDs affected the teachers' fidelity differently, and the impacts were transferred to students' academic achievements. The PDs observed in this study were provided for over three years from

2008 to 2010. The results from the present study showed that the period of the

cumulative hours attending to PDs was a good predictor of teachers' score of STEM

PBL implementation, and the sustained PDs gave a positive impact on teachers'

enactment of STEM PBLs in schools.

However, this study also brings about doubt relating to the sustainability of PD's

impact. The result of the study indicated that the teachers' attending hours to PDs was

not a good predictor of the teachers' observation ratings any more when the intervention

was terminated. It is a unique finding of the present study in terms that other studies did

not examine the impacts coming from the removal of PD on teachers. That is, the

impact of PDs from 2008 to 2010 has not been maintained by teachers until 2011. The

results infer a critical implication that the effect of PDs may not continue as much as PD

providers expect, which implies that teachers need to be involved in PDs continuously

and the effects from PDs could not be continued in a few years. This is a reason why

professional learning communities should be emphasized to guarantee teacher's lifelong

education (Erickson et al., 2005; Guskey, 2003; van Es, 2012).

The findings of the present study support that PD was effective for teachers at

least to adopt the new conceptions on the education reform. Teachers could recognize

that the education reform, such as STEM PBL, required different abilities compared to

the traditional classrooms through PDs (Newell, 2003). Teachers were able to

understand and explain what STEM PBL is in comparing it with the knowledge-centered

or teacher-centered instruction. Most teachers observed in this study acknowledged that

STEM PBL is critical and effective to stimulate students' interests and to improve students' understanding of contents.

However, teachers sometimes presented little different enactments to what PD providers intended. Some teachers did not change their own instructional strategies, or others got misconceptions from PDs. As indicated in the study by McLeskey (2009), teacher practice was less changed than their conceptions on STEM PBL, even though PDs observed in this study were more like a learner-centered PD rather than expert-centered PD. This is why feedback following PDs is necessary to pursue teachers to change their instructional approaches and to maintain the correct contentions on STEM PBL. For example, the participating teachers showed less control over their students and sometimes sat by and just watched students' performances. These behaviours came from the belief that STEM PBL should be student-centred. Moreover, the interdisciplinary feature of STEM PBL caused teachers to focus more on other disciplines without the rigorous mathematics content.

This study also illustrated teachers' challenges in implementing STEM PBL in the secondary schools (Ozel, 2008; Ward & Lee, 2002). Teachers' attitude in implementing STEM PBLs has not been changed as much as their conceptions on STEM PBL. That is, teachers were taught and recognized the features of STEM PBL; however, they were not willing to do STEM PBLs if not required. The PDs in this study were implemented as a top-down approach, and teachers assisted that this approach caused the low quality of enactment of STEM PBLs with students' stresses in engaging several projects simultaneously. Moreover, teachers still believed that traditional classes

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were more effective for taking tests in schools, and organized the traditional classes just before the tests.

To sum up, this study examined the effect of PDs by both quantitative and qualitative approaches. Our five teachers' beliefs differed from their classroom enactments of PBLs. Many PDs have been conducted to improve teachers' understanding of PBL. However, teachers often do not fully comprehend new instructional reform methods and they implement them differently because of their alternate understanding or beliefs about these methods and their importance with students in their classrooms. If teachers poorly implement PBLs, students' content achievement, beliefs, self-efficacy, and motivation can be negatively influenced. The findings of this study may be used to ensure the developed PD for teachers by informing the fact that teachers' understanding cannot guarantee the quality of implementation of STEM PBL. This multiple case study in this research is of importance because the findings of the qualitative approach provide criteria and feedback for the evaluation of PDs. It describes the individual teachers' understanding and implementation of STEM PBLs in details and compares them with one and other. This present study can help inform the efforts to enhance the quality of STEM PBL education for both teachers and their students.

CHAPTER III

THE EFFECT OF STEM PBL ON HISPANIC AND AT-RISK STUDENTS'

MATHEMATICS ACHIEVEMENT

STEM has been regarded as a critical field that ensures a financially sound national economy. At the same time, it is also true that students have been under-enrolled in STEM classes. College students have been avoiding majors leading to STEM professions. Additionally, the participation of minority groups in terms of gender, ethnicity, and socioeconomic status has been underrepresented among STEM majors in college and in the professions (Barber, 1995; Mullen, 2001; Powell, 1990). Minority students have demonstrated less interest than others in mathematics and receive lower scores on standardized national tests (U.S. Department of Education, National Center for Education Statistics, 2003; Hennesey, 2007; Mann, 2009).

Among minority groups, Hispanic students have shown low academic achievement in STEM fields, especially in mathematics (Hemphill & Rahman, 2011; Strutchens & Silver, 2000; Tate, 1997). Hispanic students' low academic achievement has been regarded as a critical issue which needs improvement, because Hispanics are one of the largest and fastest-growing racial and ethnic groups in the U.S. (Hemphill & Rahman, 2011). In spite of the huge investment in developmental mathematics programs (Abedi, Courtney, Leon, Kao, & Azzam 2006), the achievement gap between Hispanic and White students has not been reduced since 1990 (Hemphill & Rahman, 2011). In addition, in 2009 Hispanic students showed the highest school dropout rate among the

four major ethnic groups (i.e., African American, Asian, Hispanic, and White) (Chapman, Laird, Ifill, & KewalRamani, 2011). Therefore, diverse educational reforms must be implemented to increase the rate of school completion for Hispanics and to encourage their interest in learning and academic achievement.

Students who were in-danger of dropping out of school or classes were designated as at-risk. Without question, at-risk students demonstrated low achievement in STEM fields (Evans, 2004). In other words, their low academic achievement was the main reason they dropped out (TEA, 2011). Furthermore, previous studies found that attempts to improve at-risk students' scores increased the possibility of their graduation completion rates (Thompson & Kelly-Vance, 2001). Therefore, examination of the effectiveness of STEM PBL for at-risk students may show that STEM PBL contributes to increasing at-risk students' graduation completion rates as well as their academic achievement in mathematics.

To resolve the problem associated with STEM fields in schools, STEM PBL has been developed by educators as a targeted strategy and instructional method that can be implemented by teachers. STEM PBL is one of the student-centered methodologies using a ―well-defined outcome with an ill-defined task‖ to spark interest and to tap prior knowledge in building new concepts and understanding (Capraro & Slough, 2008, p. 2). However, compared to the interest in STEM PBL, there have been few experimental studies (Barron et al., 1998; Lou et al., 2011) examining the effectiveness of STEM PBL in relation to students' academic achievement. More studies have been focused on the change of students' attitudes and behaviors toward STEM content (Awang & Ramly,

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2008; Blumenfeld et al., 2000; Wah & Chu, 2009). STEM PBLs consist of diverse hand-on-activities, communication and collaboration with peers. The group-focused activities help students develop more positive attitudes and reduce anxiety toward science and mathematics (Blumenfeld et al., 2000). However, students' academic success through STEM PBL classes can be evaluated only in the presence of teachers' fidelity to the program (Stearns et al., 2012), environment, and students' abilities. That is why further research on students' academic improvement through STEM PBL is necessary. The present study will examine how implementation of STEM PBL in classrooms has an impact on students' academic achievement in mathematics, especially those who are Hispanic and at risk.

Literature Review

Hispanic Students in Schools

Hispanics are the largest minority in terms of academic performance in schools in the U.S. (Capraro, Capraro, Yetkiner, Rangel-Chavez, & Lewis, 2009; Hemphill & Rahman, 2011; Stevens, Olivares, & Hamman, 2006; Strutchens & Silver, 2000; Tate, 1997). According to Hemphill and Rahman's report (2011), Hispanic students have never outscored White students on any mathematics assessment. The gap in academic achievement in mathematics between Hispanic and White students has not been reduced, and has even increased as students became older (Hemphill & Rahman, 2011). Stevens et al. (2006) also reported that the gap in mathematics performance between Hispanics and Whites was larger than that between African Americans and Whites. Hispanic students' low academic achievement is a critical and urgent issue associated with their

dropout rate from courses and schools. In Chapman et al.'s study (2001), Hispanic students demonstrated a higher dropout rate (19.0% and 16.1% for males and females, respectively) than any ethnic group (cp., Whites, non-Hispanics (6.3% and 4.1% for males and females, respectively) and Blacks, non-Hispanics (10.6% and 8.1% for males and females, respectively)) in 2009.

Researchers have noted several factors involved in Hispanic students' low performance in schools (Hemphill & Rahman, 2011; Stevens et al., 2006; Strutchens & Silver, 2000; Tate, 1997). Hispanic students' diverse individual and environmental factors have been identified as reasons for their low academic achievement and school completion rates. First, the high number of English language learners (ELL) among the Hispanic population has been indicated as a critical reason (Escamilla, Mahon, Riley-Bernal, & Rutledge, 2007; Han, 2010; Townsend, Filippini, Collins, & Biancarosa, 2012). Secondly, Hispanics' low socioeconomic status was examined as a factor related to Hispanic students' low performance in schools (Roosa et al., 2012). Lastly, Hispanic families differ with regard to valuing school achievement, in that they tended to emphasize a family centric view (Roosa et al., 2012). That is, students in Hispanic families were expected to assume greater responsibility for taking care of their families, rather than focusing on their school work. Some strategies have been developed to compensate for the three factors influencing Hispanic students' academic achievement (Capraro et al., 2009). However, no previous studies have examined the effectiveness of implementing STEM PBL activities especially with Hispanic students.

At-Risk Students in Schools

The term ―at-risk" has been used to label students who are deemed likely to fail

during their school years. According to the *American Heritage Dictionary*, the term is

defined as ―being endangered, as from exposure to disease or from a lack of parental or

familial guidance and proper health care." However, in educational studies, the term ―at

risk" has been given various meanings in relation to student failure in schools, thus the

meaning of the term ―at-risk" is recognized differently in each study. Some have argued

that every child is at risk in some way and to some extent, whereas, others claimed that

only children who have had substantial economical, emotional, and physical disabilities

were at risk (Moore, 2006). A consensus about the term ―at risk" is critical for education

researchers who are studying students and schools (Moore, 2006). A standardized and

robust definition of the term ―at-risk" can stimulate teachers, administrators, and policy

makers to communicate actively. Without agreement on the meaning of ―at-risk", these

educational professionals may provide different solutions for at-risk students based on

their different understandings of the term. Therefore, the definition of the term should be

decided among education professionals in order to provide consistent policies for at-risk

students.

As used in this study, the term ―at risk" refers to students who underperformed

on the state test, had limited English proficiency, and/or were in the care of a state

agency (TEA, 2011). A student is identified as at risk of dropping out of school based on

state-defined criteria that are described with 13 categories (TEA, 2011). According to

the TEA definition of ―at-risk," students, who may drop out of school as well as those

who have physical or home environmental disabilities, are primarily regarded as at risk. At-risk children's groups have been under-represented in academic achievement (Mullen, 2001). That is, whether students are at risk or not is a critical factor influencing students' academic improvement. Therefore, at-risk students must receive more attention from teachers in school and from parents at home, and education researchers need to find ways to address the disadvantages of at-risk situations.

Researchers have designed programs specifically for at-risk students and examined their effectiveness in terms of the improvement in their academic performance. For example, a validated problem-solving instruction program was implemented for students who were deemed at risk, and was determined to be effective (Fuchs et al., 2008). In addition, a school-based mentoring program contributed to reducing office referrals of at-risk students and improving their school attitudes (Converse & Lignugaris, 2008). In comparison alternative school settings were ineffective for at-risk students, while students in traditional schools showed higher academic achievement in mathematics (Beken, Williams, Combs, & Slate, 2009). However, the research methodologies employed to examine the effectiveness of interventions for at-risk students were not rigorous enough to show more accurate results in controlling students' diverse individual and environmental factors.

STEM PBL

STEM PBL has been developed from a well-known instructional method based on engineering principles to improve students' problem-solving skills, communication skills, and deep understanding of content. One of the critical strengths of STEM PBL is

engaging students in solving problems within the project individually and in groups while they explore strategies to solve problems and apply content knowledge to real world problems. Throughout the project, students can apply previous or recently learned knowledge to find strategies to solve problems and recognize meaning in their lives (Capraro & Slough, 2008).

STEM PBL is not just an acronym to represent a new instructional method including four subjects, but a holistic, reformed curriculum. That is, extensive preparations associated with students, teachers, textbooks, and methods of evaluation are required for STEM PBL to be effective. Preparing for a STEM PBL class, teachers need to suggest an *ill-defined task* to students (Capraro & Slough, 2008). That task should have several solutions rather than one. In addition, it must be solved after students think hard about it, not just remember certain knowledge. In addition to including diverse problems, STEM PBLs projects also require students to engage in six processes (i.e., problem and constraints identification, research, ideation, analysis of ideas, testing and refinement, and communication and metacognition) and behaviors (i.e., read books, brainstorm, search on web sites, do hands-on activities, and communicate with their group members) (Moran, Moon, & Barroso, 2008).

STEM PBL instruction should look different from traditional instruction. In STEM PBL classes, learning should be a constructivist, collaborative, and contextual process (Clark & Ernst, 2007; Dolmans, Grave, Wolfhagen, & Vleuten, 2005). STEM PBLs should contain rigorous subject area content and creative and unique tasks leading students to higher order thinking. Students are expected to construct their own

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knowledge through STEM PBL. This means that students should reflect on their prior

knowledge, actively apply it to solve problems, and finally, construct their own

knowledge. Hands-on activities in STEM PBL make learning more contextual. Diverse

hands-on activities motivate students to be eager to complete the project and make them

more self-directed and collaborative (Clark & Ernst, 2007). In addition, open-ended

questions during STEM PBL activities allow students to depart from the standard

pattern. In the traditional classrooms, students were asked to answer multiple-choice

questions that normally have only one correct answer. In traditional classrooms, teachers

were more likely to force students to memorize knowledge without thinking about what

they were learning, why they had to learn or how they could apply knowledge in their

daily lives. In contrast, STEM PBL instruction does not ask students a question that has

only one answer. Giving students opportunities to think more is one of the main

purposes of STEM PBL (Capraro & Slough, 2008).

Researchers have reported the positive impacts of implementing STEM PBLs in

schools. STEM PBL was effective in improving students' attitude and academic

performance (Capraro et al, 2012; Kaldi et al., 2011). First, involvement in STEM PBLs

enriched students' knowledge of content (Kaldi et al., 2011). The positive impact of

engagement in STEM PBLs on students' test scores was examined with elementary

(Kaldi et al., 2011), secondary (Chang & Lee, 2010; Lou et al., 2011), and post-

secondary (Baran & Maskan, 2010; Domínguez & Jaime, 2010; van Rooij, 2009)

students. Second, implementation of STEM PBLs is a potential strategy in improving

students' thinking and metacognitive skills. While engaged in a project, students have

more opportunities to experience diverse field-based activities and apply their prior knowledge to problems relating to the real world. The process of connecting their prior knowledge with present problems requires a higher level of thinking skills, and finally, contributes to developing students' metacognitive skills. In addition, hands-on activities as part of STEM PBL led students to think of problems more concretely and help them try various strategies (Kaldi et al., 2011; Lou et al., 2011). Third, students value collaborations and communications with peers, and show higher self-efficacy in learning content when involved in PBL activities (Kaldi et al, 2011; Lou et al., 2011; van Rooij, 2009). Throughout the project, students more often participate in discussions and share their knowledge with peers. Moreover, students can achieve higher self-efficacy with less anxiety in learning by successfully completing the project in a group.

However, the effectiveness of STEM PBL engagement on student academic performance in schools has not been studied sufficiently, especially considering students' individual factors. Therefore, this study aimed to investigate how STEM PBL influences Hispanic and educationally at-risk students in terms of their academic achievement in mathematics.

Hypotheses and Research Questions

The present study was implemented on the basis of hypotheses grounded in previous studies. First, we hypothesized that STEM PBLs would have positive impacts on Hispanic students and at-risk students' performances in mathematics classrooms and would result in higher academic achievement across years. Hispanic and at-risk students may receive more positive impacts from engagement in STEM PBL because related

activities may be more likely to reduce their anxiety, and group collaborations may provide them more self-confidence. Second, the academic achievement growth rate of Hispanic and at-risk students across years may be higher than that of other groups because of the sustainability of STEM PBL classrooms and the accumulation of positive impacts. Third, the academic achievement gap between Hispanic and other ethnic groups may be reduced, in direct contradiction to the current situation. Therefore, we employed a latent growth model to analyze students' academic achievement accompanied by individual factors to answer the following research questions:

1. Is STEM PBL effective for Hispanic students in terms of their growth rate in mathematics scores longitudinally across three years?

2. Is STEM PBL effective for at-risk students in general in terms of mathematics scores longitudinally across three years?

3. Among at-risk students, is STEM PBL as effective for Hispanic and non-Hispanic students in terms of growth rate in mathematics scores longitudinally across three years?

Method

Participants

The participants were 3,394 high school students who were selected from among the 392,974 high school students in Texas. To answer the research questions, the participants were selected by the following inclusionary criteria. First, participants were in the same region, in which three schools had been provided PD by a STEM center at a southwestern research university. Second, participants scored below the median

(Median=34) on the 2009 Texas Assessment of Knowledge and Skill (TAKS) mathematics test. The reason for selecting students who scored below the median was to minimize the variance of scores between groups (i.e., students who were engaged in STEM PBL schools and those who were not). One thousand seven hundred and fifteen students (50.5%) were female, and 1,677 students were eligible for free or reduced-price meals under the National School Lunch and Child Nutrition Program. Regarding ethnicity, 1,304 (38.4%), 1,257 (37%), 819 (24.1%), and 14 (0.4%) students were African American, White (not of Hispanic Origin), Hispanic, and Asian or Pacific Islanders, respectively. 182 (5.4%) students were participating in a special education program, and 2,399 (70.7%) students were designated as at risk of dropping out of school under state-mandated academic criteria only.

Of the 3,394 recruited participants, 528 (15.6 %) were identified as students enrolled in the three schools who had engaged in STEM PBLs in classrooms from 2008 through 2010. The rest, 2,866 students, were enrolled in 56 different schools in the same region. Analyses of the students' scores on the TAKS mathematics test at baseline (Year 1) did not indicate any difference between the 528 STEM PBL and the 2,866 non-STEM PBL students. Teachers in these three schools participated in a sustained program of PD provided by one STEM center. The teachers were required to implement a series of STEM PBL activities in their classes. Students were continually involved in STEM PBL activities implemented by their teachers in science and mathematics classes from 2008 to 2010.

Research Design

The intervention program in the study was a sustained and well-structured PD program on STEM PBL for high school in-service teachers. For three years, teachers were required to attend 10 days of PDs a year, 7 hours per day, in addition to classroom follow up and observations of PD components in their classes. The school district's curriculum specialists and supervisors were trained to use the classroom observation instruments to provide feedback to teachers when the research team was not in the schools. Content specialists (professors, project managers, and doctoral students in STEM fields) designed modules covering the scope of STEM PBL, instructional theories, practical examples, lesson plans, and rubrics for STEM PBL classrooms. In addition to the 210 formal PD hours, teachers and content specialists formed professional learning communities within each school to support incorporation of STEM PBL ideas. Teachers designed lesson plans utilizing STEM PBL and shared them with specialists. Furthermore, specialists observed teachers' STEM PBL classes and had a chance to provide feedback in terms of STEM PBL structure, STEM PBL facilitation, student participation, resources, assessment, and classroom learning environment.

While student achievement was the main variable of the interest in this study, the effect of any results is an indirect evaluation of PD effectiveness. To examine the effect of STEM PBL on students' academic performance, we designed research comparing students' standardized test scores and growth rates across three years. We first determined the year and the grade in which students took the first TAKS test after the three schools had completed their sustained PD. We suggested a main model to examine

the effect of STEM PBL especially for Hispanic and at-risk students. In addition, we analyzed a supplementary model for at-risk students only, and confirmed the effect of STEM PBL on Hispanic students' academic achievement in mathematics.

Data Sources

The data set of the present study was hierarchical, with three levels: repeated measures across three years (Level 1) were nested within students (Level 2), and students were nested within schools (Level 3). In this study, the school variable was recoded into a student variable indicating whether each student had been taught in STEM PBL classrooms. Therefore, latent growth models with two levels were employed. On Level 1, students' TAKS raw scores for three years were used, and the years were coded as 0, 1, and 2 for 2008, 2009, and 2010, respectively. On Level 2, the present study included six variables representing individual student factors (gender, ethnicity, socioeconomic status, special education, at-risk, and ESL).

The state accountability instrument, TAKS, provided empirical data (2008 to 2010). Students took this mandated test once a year. In a study, like the present one using a standardized test, we have to assume that the scores were reliable because individual item responses for each student were not available and test publisher reports indicated reliability in excess of 0.81 (TEA, 2008).

Data Analysis

To capture the trajectory of students' academic achievement impacted by STEM PBL, latent growth analyses were employed. The latent growth model employed in educational studies has the following benefits: (a) to identify not only the individual's

trajectory of academic achievement (i.e., within), but also the differences between individuals across years (i.e., between); (b) to fit the data into either a latent growth linear or curve model; (c) to design multi-level and multivariate analyses; (d) to offer proper adjustment for missing data; and (e) to provide the extent to which the variance was further explained by adding more variables (Ho, O'Farrell, Hong, & You, 2006; Meredith & Tisak, 1990). For these reasons, the latent growth model was appropriate for the study. In addition, the latent growth model employed allowed for multiple predictors (i.e., gender, ethnicity, economic status, ESL, special education, educational risk, and STEM PBL), and running the analyses with missing data.

Null Model

The latent growth model employed in this study is represented in Figure 2. The proposed latent growth model provided estimations of an intercept and slope of the overall growth trajectory. That is, the intercept and slope represented the growth trajectory line of all of the students. In addition, main and interaction effect estimations of each covariate could explain the associated differences from the intercept and slope of the entire data set. For example, the main and interaction effect of the variable STEM PBL would differentiate students who had learned in STEM PBL classrooms and those who had not. Based on the research questions, several interaction effects were examined (i.e., time × STEM PBL, time × ethnicity, time × STEM BPL × ethnicity, time × at-risk, time × STEM PBL × at-risk), which indicated the extent to which the predictors (i.e., STEM PBL, ethnicity, and educational risk) had influenced the students' mathematics academic achievement.
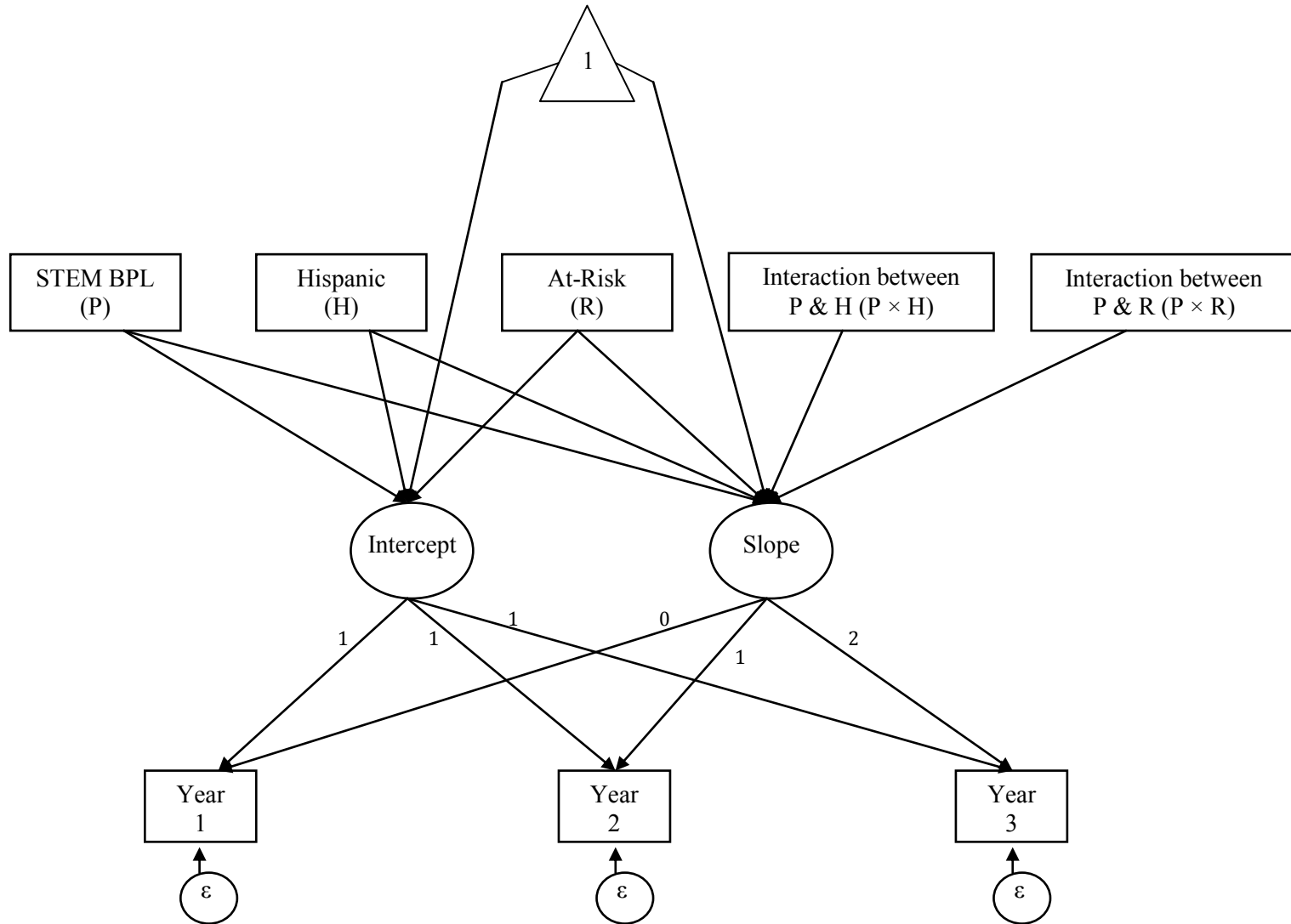
Figure 2. Latent growth model.

Results

Descriptive Statistics

Descriptive statistics, including means, standard deviations, and correlation coefficients for the predictors in the hypothesized latent growth model, are reported in Table 2. As expected, students' academic achievement was highly related to economic status, ESL, special education, at-risk, and ethnicity. Students who were economically disadvantaged, educationally at risk, Hispanic, and in ESL and special education programs were more likely to have lower scores on the TAKS mathematics test.

Unconditional Latent Growth Model

The unconditional latent growth model was analyzed to test the changes in trajectories of students' mathematics scores across three years. We ran the analyses including this model using Mplus 7 with the full information maximum likelihood (FIML) estimation method (Muthén & Muthén, 1998-2011). The unconditional latent growth model with two growth factors (i.e., intercept and slope) had fair fit according to suggested criteria ($\chi 2$ (8) = 103.103, $p < .01$; root-mean-square error of approximation (RMSEA) = 0.173; standardized root-mean-square residual (SRMR) = 0.094; comparative fit index (CFI) = 0.886). The estimations of the intercept and slope were 24.090 and 4.056, respectively. We ran the unconditional latent growth model to examine the effects of predictors by comparing trajectories of students' academic achievement across the three years, because the fit was adequate to ran subsequent latent growth model.

Table 2

Descriptive statistics and correlations among predictor variables for the analysis

	Predictors (1~3)			Covariates (4~7)				Outcomes (8~10)		
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Correlations										
1. STEM PBL	–									
2. Hispanic	0.277**	–								
3. At-Risk	0.059**	0.047**	–							
4. Gender	-0.004	0.003	0.037*	–						
5. SES	0.346**	0.221**	0.177**	-0.003	–					
6. SE	-0.041*	-0.070**	0.127**	0.089**	0.037*	–				
7. ESL	0.140**	0.225**	0.082**	0.011	0.129**	-0.030	–			
8. Academic score 2008	-0.046**	0.014	-0.199**	-0.070**	-0.131**	-0.247**	-0.044**	–		
9. Academic score 2009	-0.019	-0.038	-0.218**	-0.014	-0.110**	-0.140**	-0.040	0.516**	–	
10. Academic score 2010	-0.086**	0.016	-0.151**	-0.022	-0.145**	-0.158**	-0.084**	0.376**	0.432**	–
Descriptive Statistics										
Mean	0.160	0.241	0.71	0.495	0.490	0.050	0.020	24.34	27.90	34.66
SD	0.362	0.428	0.455	0.500	0.500	0.225	0.125	6.638	9.105	11.008

Note. STEM PBL = Science, technology, engineering, and mathematics project based learning; ESL = English as a second language; Ethnicity was coded as 1 for Hispanic and 0 for others (i.e. African American, White (not of Hispanic Origin), and Asian or Pacific Islanders). **$P<0.01$, *$P<0.05$.

Stage 1: STEM PBL Latent Growth Model

We first ran the latent growth model with three main effects (i.e., ethnicity, at risk, and STEM PBL) and two interaction effects (i.e., STEM PBL× ethnicity and STEM PBL× at-risk), while controlling for four covariate variables (i.e., gender, socioeconomic status, special education, and ESL). The hypothesized model adequately fit the data ($\chi 2$ (16) = 147.327, $p < .01$; RMSEA = 0.049; SRMR = 0.078; CFI = 0.900). As shown in Table 3, there was not difference between the two groups at the baseline year (STEM PBL). That is, the difference in academic achievement between students in the three STEM PBL schools and in the non-STEM PBL schools was not statistically significant (β=-0.192, $p > 0.05$) at the onset and the growth rate remained consistent after three years. On the key variable of Ethnicity, Hispanic and non-Hispanic were the same at the beginning of the study (β= -0.489) and there was no difference in the growth rate across the three years. The variable of at-risk was a good predictor of the intercept as well as slope (β=-2.328, $p < 0.05$; β=-0.658, $p < 0.05$). At-risk students showed lower initial status and growth rate than non-at-risk students.

Table 3

Unstandardized direct effect of predictors on two growth factors

Predictors	STEM PBL Est. (SE)	Hispanic Est. (SE)	At Risk Est. (SE)	STEM BPL×Hispanic Est. (SE)	STEM BPL×At Risk Est. (SE)
Intercept	-0.192 (0.343)	0.489 (0.285)	-2.328* (0.256)	–	–
Slope	-0.669 (0.777)	-0.600 (0.410)	-0.658* (0.320)	1.832* (0.756)	-0.371 (0.798)

Note. STEM PBL= Science, technology, engineering, and mathematics project based learning; STEM PBL was coded as 1 for students who enrolled in STEM PBL schools, and 0 for students who enrolled in other schools. Ethnicity was coded as 1 for Hispanic students and 0 for others (Asian or Pacific Islander, African American, and White, not of Hispanic Origin). At Risk was coded as 1 for students who were designated at risk of dropping out of school under state mandate, and 0 for students who were not. * $P < 0.05$

Based on the parameter estimations of predictors, the intercepts and slopes of the trajectories for each group were computed (see Table 4). We were first interested in the two predictors (i.e., STEM PBL and ethnicity); therefore, four trajectories were created from the latent growth analysis. On the intercept, STEM PBL and ethnicity predictors were not statistically significant, and Groups 1, 2, 3, and 4 had the same initial score in the base line (see Figure 3). The interaction effect between STEM PBL and ethnicity had a statistically significant impact on the slope, whereas main effects, STEM PBL and ethnicity did not. Therefore, the growth rate of Hispanics in STEM PBL schools (Group 1) was higher than that of the other three groups (see Figure 3). Additionally, we computed the effect sizes, Hedges g (2007), the standardized effect size of this interaction effect was 0.453 which was the relatively large effect. Next, we were interested in the two predictors, STEM PBL and at-risk. In the same way, four trajectories were created from the latent growth analysis. The predictor at-risk statistically significantly predicted the student scores on the intercept as well as the slope, with the corresponding standardized effect sizes equal to 0.576 and 0.163, respectively. However, the interaction effect between STEM PBL and at-risk was not statistically significant. Therefore, regardless of whether at-risk students were engaged in STEM PBL, on average at-risk students had a lower growth rate than non-at-risk students (see Figure 3).

Table 4

Intercepts and slopes for STEM PBL by ethnicity and STEM PBL by at-risk for each group

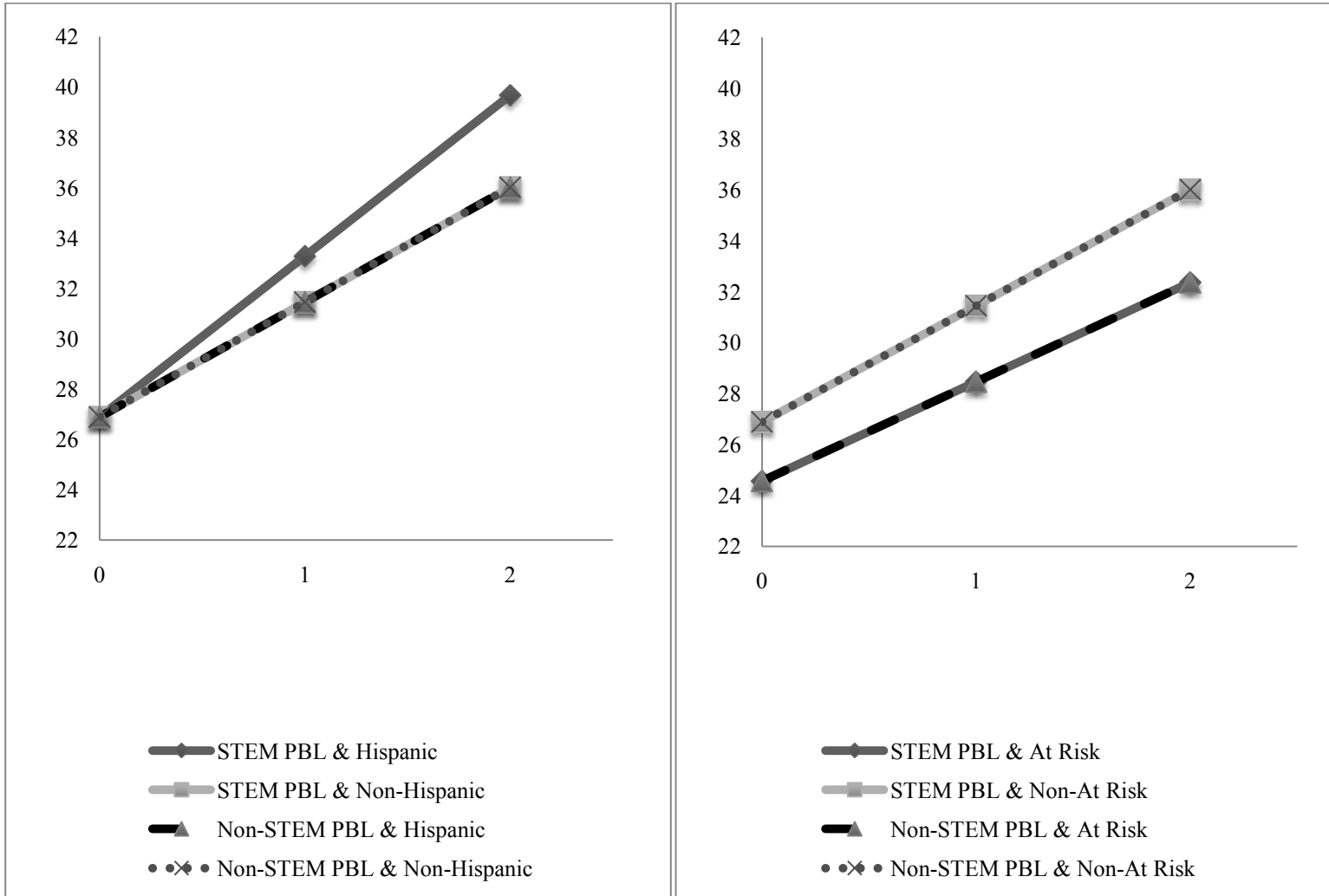| Group	Intercept	Slope
Group 1. STEM PBL & Hispanic	26.887	6.394
Group 2. STEM PBL & non-Hispanic	26.887	4.562
Group 3. Non-STEM PBL & Hispanic	26.887	4.562
Group 4. Non-STEM PBL & non-Hispanic	26.887	4.562
Group 5. STEM PBL & At Risk	24.559	3.904
Group 6. STEM PBL & non-At Risk	26.887	4.562
Group 7. Non-STEM PBL & At Risk	24.559	3.904
Group 8. Non-STEM PBL & non-At Risk	26.887	4.562

Figure 3. Trajectories of student academic achievement in mathematics from 2008 to 2010.

Stage 2: Supplementary Analysis

To determine the effectiveness of STEM PBL on Hispanic students, we ran the supplementary analysis only with at-risk students (n=2,399). The model showed adequate fit: $\chi 2$ (13) = 123.288, $p < .01$; RMSEA = 0.059; SRMR = 0.036; CFI = 0.862. Of 2,399 at-risk students, 610 students were Hispanic (25.4%). The results of the analysis of at-risk students agreed with the prior results of this study. In other words, STEM PBL and ethnicity were again not statistically significant on the intercept. However, the effect of ethnicity predictor alone was statistically significant on the growth rate (β= -0.942, $p < 0.05$), with the standardized effect size equal to 0.241. This means that Hispanic students across both groups (STEM PBL and non-STEM PBL) had a lower growth rate than students of other ethnicities. In addition, the interaction effect between STEM PBL and Hispanic was statistically significant (β= 2.119, $p < 0.05$), with the standardized effect size equal to 0.540. Finally, Hispanic students in the STEM PBL schools had a higher growth rate than others (non-Hispanic students in STEM PBL schools and all students in non-STEM PBL schools) (see Figure 4).
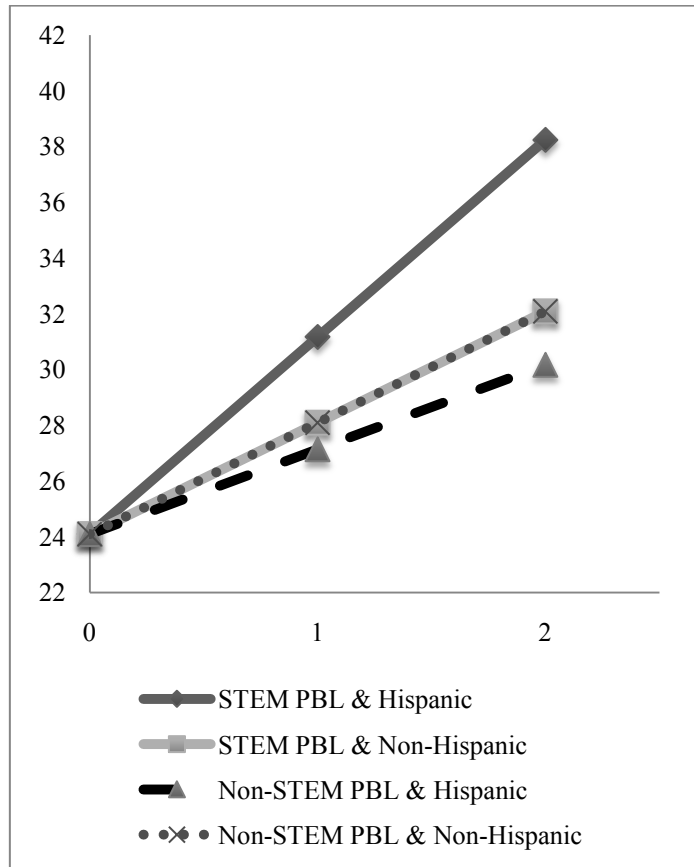
Figure 4. Trajectories of at-risk student mathematics achievement from 2008 to 2010.

Discussion

In this study latent growth models were used to investigate trajectories of

students' mathematics achievement where STEM PBL was implemented in schools, and

to compare those trajectories with those of students enrolled in non-STEM PBL schools.

Of special interest was the effectiveness of STEM PBL for Hispanic and at-risk students.

Latent growth modeling provided the mechanism by which the data provide insights into

the research questions. The sophisticated analytic technique shows that that overall

interaction effects for STEM PBL and individual student factors (i.e., ethnicity and at-risk) varied, indicating that STEM PBL was more or less effective for specific student groups than for the comparison groups. The results of this study show differential effects and provide a clear rationale for a closer examination of STEM PBL factors that may impact Hispanic students differentially.

Hispanic students in STEM PBL instruction showed increased mathematics achievement. At baseline, Hispanic students were underachieving as compared to other ethnicities in mathematics. This is consistent with many other research studies (e.g., Capraro et al., 2009; Hemphill & Rahman, 2011; Stevens et al., 2006; Strutchens & Silver, 2000; Tate, 1997). However, the interaction effect between STEM PBL and ethnicity was statistically significant across three years. There was no statistically significant difference in slopes for Hispanic and non-Hispanic students when considering the entire sample. However, Hispanic students who participated in STEM PBL classes for three years showed higher growth rates than other students (i.e., Hispanics in non-STEM PBL schools, and non-Hispanics in STEM PBL schools). The effect estimate for students at-risk was likely impacted by the number of Hispanic students who were also at-risk. This confound was not controlled for because the important indicator was for the general at-risk population and not just Hispanic at-risk. It is possible that Hispanic at-risk students may have performed better than other others but this was not a primary research interest. This finding is similar for Hispanics who engaged in an intervention consisting of intense language development (Capraro et al., 2009). In that study, the Core Plus mathematics program is like STEM PBL because

they both commonly include integrated developments of fundamental concepts, student-centered investigations, structured mathematics language development, and advanced technology usage. Because STEM PBL consists of activities that stimulate communication and collaboration, Hispanic students might have additional opportunities to develop their language proficiency and to feel more comfortable working in groups. However, this assumption is based only on previous studies (Townsend et al., 2012; Roosa et al., 2012), and could not be investigated in this study. Therefore, these factors are likely candidates for being highly relevant for future study when closing the gap in mathematics performance is important. The positive effect of .54 is not huge by quantitative research standards but can be considered large for this type of intervention (Capraro, 2004).

STEM PBL did not positively influence at-risk students in this study and there was no difference in growth rate for STEM or Non-STEM groups. The net effect is that STEM PBL was a benign treatment for at-risk students without negative consequences but also no noteworthy positive gains with regard to mathematics achievement as measured by the TAKS. It is possible that at-risk students had benefits in domains not measured in this study like affect, attitude, or socio-cognitive. This finding is consistent with research documenting the ineffectiveness of alternative school settings for at-risk students (Beken et al., 2009), but not with research verifying the effectiveness of diverse treatments for at-risk students (Converse & Lignugaris, 2008; Fuchs et al., 2008). Further research is needed to clarify the connection between components of STEM PBL and individual factors influencing at-risk students' academic achievement.

We employed latent growth modeling, because it allows for more accurate results when controlling for students' individual factors influencing academic achievement. Prior studies used simpler analytic methods (i.e., ANCOVA, ANOVA) to compare students' scores of two groups, or in pre- and post-tests (Beken et al., 2009; Converse & Lignugaris, 2008; Fuchs et al., 2008). In addition, this study used a longitudinal dataset, which presents a clearer picture of academic achievement than do students using constrained designs that may look at three consecutive grades all within the same year. By employing multi-level analysis with multi-group, we were able to retain a larger sample size and guarantee lower error variances because the analytic technique is not dependent on list wise deletion for missing data, providing greater power against Type I error (Thompson, 2006).

The findings from this study imply several suggestions for policy and practice. First, the results advocate for implementing STEM PBL activities with Hispanic students in general and at-risk Hispanic students for whom mathematics learning may improve. In addition, STEM PBL may be implemented in classrooms with a high number of Hispanic and at-risk students to reduce their dropout rate from school and classes. As revealed by various researchers (Capraro et al., 2012; Kaldi et al., 2011; Lou et al., 2011; van Rooij, 2009), STEM PBL was effective in improving students' positive attitudes in school as well as their test scores. Because Hispanic students showed the highest school dropout rate (Chapman et al., 2001) STEM PBL seems like a potentially beneficial program for improving achievement and through this increased achievement potentially decrease the dropout rate for Hispanic students. .

The results of this study cannot generalize to Hispanic students whose scores were above the median in mathematics or to at-risk students in general. In addition, the small sample size of the STEM PBL subgroup in this study might have decreased the power in the analysis in spite of the overall large sample size. Therefore, the obtained *p*-values may not actually reflect the true case but we expect the obtained effects to be stable within the 95% confidence interval. Furthermore, only one learning-environmental factor could be considered in the analysis because of the data limitation, even though teachers' fidelity to enact STEM PBL was indicated as a critical factor influencing students' performance (Stearns et al., 2012). Lastly, the study did not undertake a detailed examination of processes that may explain why STEM PBL activities positively influenced Hispanic students in their growth rates, or why at-risk students in general were not statically or practically significantly influenced by engagement in STEM PBL activities. We recommend that further studies investigate the paths connecting components of STEM PBL to students' individual factors, which may yield further evidence of effectiveness of STEM PBL on each student group and reveal what components should be involved for implementing the most effective STEM PBLs in classrooms.

CHAPTER IV

HOW STEM PBL DIFFERENTLY AFFECTS HIGH, MIDDLE, AND LOW

ACHIEVERS: THE IMPACT OF STUDENT FACTORS ON ACHIEVEMENT

The main purpose of the present research was to investigate the impact of STEM PBL on student's academic achievement when considering individual student factors. Students may exhibit differential achievement within the same learning environment. The most appropriate learning environment can differ for each student by characteristic. For example, female and male students who were taught by the same teacher with the same textbook showed varied achievement scores (Benbow, 2012; Matteucci & Mignani, 2011). Furthermore, homogeneous student groups favored higher achievers, whereas heterogeneous grouping was more effective for low achievers (Chen et al., 2008; Hooper & Hannafin, 1988; Robinson, 1990). No learning environment can be guaranteed as the best milieu for every student without considering other complicated and possibly confounding factors.

Student achievement is influenced by individual factors. A student's gender, ethnicity, SES, and language proficiency were indicated as critical factors affecting academic achievement (Konstantopoulos, 2009; Lubienski, 2002; Ma & Klinger, 2000; Shores et al., 2010; Tate, 1997). Because these factors influenced student achievement differentially, diverse, complex, and varied combinations of these factors showed a differential impact on achievement (Hansen & Jones, 2011; Ma & Klinger, 2000; Tate, 1997). For example, students' scores indicated important differences by gender;

however, the difference in mathematics was smaller than in other subjects, i.e., science, reading, and writing (Konstantopoulos, 2009; Ma & Klinger, 2000; Shores et al., 2010). SES was a critical predictor of mathematics achievement even if other student and school variables were controlled (Ma & Klinger, 2000). The influence of ethnicity varied according to study designs and evaluating objectives (Capraro, 2001; Ma & Klinger, 2000). In addition, the impact of language proficiency on mathematics achievement varied according to student's ethnicity (Tate, 1997). The gender factor showed a larger difference for Black, Pakistani, and Bangladeshi students than for White children (Hansen & Jones, 2011).

Literature Review

Student Factor: Achievement Level

Diverse levels of achievement among students exist in a classroom, and teachers change their instructional approaches based on their beliefs, attitudes, and expectations of students' ability levels (Babad, 1990; Richardson & Fallona, 2010). Student achievement level was one critical factor teachers' used when deciding an instructional method which in turn has been shown to impact achievement for those students in subsequent years (McKown & Weinstein, 2008). For example, a student-directed and self-regulated learning environment where the teacher acted as a guide to assist the students' learning process was shown to be more effective for students who had higher achievement (Yoon, 2009). On the other hand, low achievers exhibited less of a desire for learning, self-control, and self-management indicative of insufficient readiness for self-directed learning; therefore, teachers were advised to be more deeply involved in the

learning processes for low achievers (Abraham et al., 2011). Moreover, problem solving combined with a computer adventure game intervention was also shown to be an effective method for improving low achievers' mathematics scores (Kajamies, Vauras, & Kinnunen, 2010). The interactive and stimulated components of the game intervention were more appropriate and effective with low achievers.

Case by case, high and low achievers responded diversely to different instructional approaches. For example, high, average and low mathematics achievers displayed no meaningful differences in achieving benefits when using a graphing calculator (Tan, 2012). However, low achievers demonstrated more improvements than high achievers in solving problems and comprehending ecological concepts when they were engaged in peer discussions (Rivard, 2004).

STEM PBL

STEM education has been discussed as a critical issue inside and outside of schools, and large shares of funds have been invested in encouraging students and also in increasing educators' interests and efforts in STEM fields. According to the report from the Federal Inventory of STEM Education Fast-Track Action Committee and Committee on STEM Education National Science and Technology Council (2011), of the total of 3.4 billion dollars spent by US Federal agencies on STEM education, about 1.1 billion dollars was invested in K-12, and hundreds of programs were implemented within the boundaries of STEM education. Compared to the amount of investment, however, the effect of STEM education on K-12 education has not been studied using advanced and multifaceted methodologies to investigate the practical impacts in schools.

STEM PBL is an instructional approach embedded in K-12 classrooms for STEM education. STEM PBL is grounded in the theoretical background of constructivism where students are engaged in the diverse components of problem solving, interdisciplinary curriculum, open-ended questions, hands-on activities, group work, and interactive group activities (Capraro & Slough, 2008; Clark & Ernst, 2007; Dolmans et al., 2005). For example, in STEM PBL classrooms, students are required to solve problems and engage in ill-defined tasks within the boundary of a well-defined outcome collaborating with other group members. Effective STEM PBL should be interdisciplinary and contain diverse content objectives within the context of hands on activities to produce an artifact (Capraro & Slough, 2008). STEM PBL classrooms are more student-centered, where the teacher is expected to play a role as a guide (Clark & Ernst, 2007). STEM PBL is a new teaching strategy and learning environment for teachers as well as students. This teaching strategy can have profound effects while being implemented in classrooms. Therefore, studies to evaluate the effects of implementing STEM PBLs in schools for educators and teachers are necessary.

STEM PBL has positively influenced students' non-academic performances. Students who have experienced STEM PBL showed positive attitudes toward learning itself, team communication, and collaborative behavior (Domínguez & Jaime, 2010; Johnson et al., 1992; Kaldi et al., 2011; van Rooij, 2009; Veenman et al., 2000). Furthermore, STEM PBL was examined with respect to increasing students' interest, self-confidence and self-efficacy (Baran & Maskan, 2010), which was highly related to the components of STEM BPL such as collaborations in group work and contextual

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problems reflecting students' real world experiences. In addition, students who studied in STEM PBL classrooms were less likely to drop out of courses and school (Domínguez & Jaime, 2010). As an exceptional case, Kaldi et al. (2011) indicated that students had a difficult time and received negative feedback from students of different ethnicities during group work. For example, some students involved in group work from Romania and Roma had a difficult time working together, even though Greek primary schools have had multi-ethnic classes since the 1990s.

Compared to the studies on the impact of STEM PBL on student's attitude and perspective on learning, few studies have investigated the effect of STEM PBL on the improvement of student achievement. Baran and Maskan (2010) examined the effect of STEM PBL at the university level and presented positive effect sizes and statistically significant differences between experimental and control groups ($p < .05$). One interesting result from their study was that students' scores were statistically significantly different for comprehension, but not for knowledge and application. In addition, diverse components of STEM PBL were pointed out to improve students' academic achievement. Kaldi et al. (2011) found that hands-on activities and field-based contexts were the primary reasons for positive effects for students in content knowledge and attitude toward learning. Furthermore, students encouraged through STEM PBL type factors were required to solve problems embedded in the project which improved their problem solving skills (Barron et al., 1998; Boaler, 1997). Therefore, it is essential to develop an intervention that positively influences attitude and perspective on learning when designing an intervention especially in light of other student factors.

Student Factors and STEM PBL

To provide more effective instruction, the impact of STEM PBL should be evaluated with consideration toward individual student factors. Very little information is available on the role of student factors on learning during STEM PBL instruction (Thomas, 2000). However, research is clear that low achievers can be motivated through STEM PBL as compared to high achievers on critical thinking and group interactions (Horan, Lavaroni, & Beldon, 1996). By gender, female students preferred STEM PBL type activities and demonstrated higher achievement (Boaler, 1997).

Even though STEM PBL education has been regarded as one of the more effective teaching strategies for classes with varied achievers (Olszewski-Kubilius, 2010), there have been almost no studies concerning students of varied academic achievement performances (Thomas, 2000). The present study offers profound information about the effects of implementing STEM PBLs on mathematics achievement while considering student's diverse personal factors.

Research Questions

The purpose of this study was to investigate whether a pedagogical strategy using STEM PBL, demonstrated differential effects on mathematics achievement for students with varied performance levels (i.e., high, middle, and low), and to what extent did students' individual factors (i.e., gender, ethnicity, economic disability, LEP, ESL, special education, gifted, and at-risk) influenced mathematics achievement accompanied by their performance impact.

Methods

Participants

The participants were diverse students (N_{2008}=836, N_{2009}=533, and N_{2010}=485) enrolled in three small, urban, low socio-economic high schools from 2008 to 2010. In the present study, students who took the TAKS test in 2008 were selected, because student's performance level in 2008 was the main predictor in this study. Based on the demographics of the three schools in 2008, 412 students (49.3%) were male. Largest majority of students were Hispanic (*n*=453, 54.2%) and African American (*n*=314, 37.6%). Additionally, there were 69 White and Asian students (8.25%). We focused on the analysis to examine the differences between Hispanic and other students (i.e. African American, White and Asian), because Hispanic students were the major population and have been underrepresented in STEM subjects in this particular district. About 6.1% and 2.3% of students were categorized as ESL and special education, respectively. Approximately 85% of students were eligible for free or reduced meals under the National School Lunch and Child Nutrition Program, which was regarded as an index of economic status. In addition, 518 (62%) students were categorized as ―at‑risk". The TEA (2011)'s definition of at-risk included students who underperformed on the state test, had limited English proficiency, or were in the care of a state agency.

Participants have been influenced by STEM PBLs enacted in teachers' classrooms who attended STEM PBL PDs. These PDs were designed and implemented under a state-wide project to improve students' readiness for postsecondary majors and professions especially with low-income and low-performing students in STEM fields.

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Teachers in three high schools (i.e., one charter school and two STEM academies) were compared with those in 220 other schools. The teachers in this study attended a sustained period (30 sessions, 7 hours per session) of PD provided by one STEM center over a three-year period. Study teachers were required to teach one STEM PBL each six weeks. Teachers designed STEM PBL lesson plans and cooperated with content specialists at the STEM center thereafter to modify their lesson plans to enable the most effective STEM PBLs enacted for students. Students who were selected for this study participated in STEM PBL for three years in both their mathematics and science classrooms.

Data Collection

The data for this study were students' mathematics scores from the state accountability assessment, TAKS, which provided empirical data (2008 to 2010). The employed analytic approach included controlled covariates (i.e., students' gender, ethnicity, economic status, ESL, special education, and/or at-risk status) that may influence their achievement scores in exploring STEM PBL across years. Student's performance levels were the main predictor for the outcome variable, students' scores in 2010. Reliability coefficients were used descriptively to evaluate ―to what extent [we can] say that the data are consistent" (Huck, 2008, p. 76). The provided reliability for TAKS assessments ranged from 0.87 to .90 (reliability of TAKS-M assessments ranged from .82 to .88) (TEA, 2008; Zucker, 2003).

Data Analysis

Two methods were utilized to investigate the impact of STEM PBL on students who had varied prior mathematics achievement: descriptive statistics and longitudinal

HLM. First, descriptive statistics, including frequency, mean, standard deviation, and correlation coefficients were used to examine each variable. In addition, skewness and kurtosis of the dependent variables were reported to evaluate whether they were univariate normal.

Second, a longitudinal HLM analysis examined the two-level data using SPSS version 21.0. Considering the three-year longitudinal data, a growth model was designed with a two-level hierarchy: time and student level. At the time level, students' mathematics scores were coded into three time series. At the student level, students were divided into three groups (i.e., high, middle and low achievers) according to their 2008 TAKS mathematics performance level. The improvement in student achievement was measured by their 2010 TAKS mathematics scores. Lastly, effect sizes (i.e., Hedge's g) were employed to contextualize the magnitude of differences in means.

Grouping students into three groups was critical, because the results from the longitudinal analyses could possibly differ based on the type of grouping strategy employed. Navarro et al. (2012) used the normal distribution and standard deviation (SD) (i.e., Group 1$< \bar{X} - \sigma$, $\bar{X} - \sigma \leq$Group 2$\leq \bar{X} + \sigma$, $\bar{X} + \sigma <$Group 3). In addition, Zady, Portes, and Ochs (2003) employed some specific scores to divide groups (i.e., low achievers ≤ 50 and high achievers ≥ 70). A cumulative percentile approach was also employed to assign students into several groups (Post et al., 2010; Sticjdakem & Williams, 2004). In the current study, students were assigned into three groups by the criteria offered by the test provider, TEA. The TEA described three performance levels to divide students into groups (i.e., ‗did not meet the standard,' ‗met standard,' and

ommended performance'). Accompanied by these descriptors of three performance levels, TEA provided specific scores indicating each group. Based on the 2008 TAKS raw scores in mathematics, a score of less than 31 out of 52, indicated students did not meet the standard, a score of 31 to 44 met the standard, and students scoring 45 or above were commended performance. Did not meet the standard' meant "unsatisfactory performance; below state passing standard; insufficient understanding of the mathematics TEKS curriculum" (TEA, 2009, p. 13), whereas met the standard' indicates "satisfactory performance; at or above state passing standard; sufficient understanding of the mathematics TEKS curriculum" (TEA, 2009, p. 13). Lastly, commended performance' was equated to "high academic achievement; considerably above state passing standard; through understanding of the mathematics TEKS curriculum" (TEA, 2009, p.13). Thus these three student groups were regarded in this study as low, middle, and high performance groups for convenience.

Depending on the main interests associated with the research questions, we decided the reference groups of each predictor and covariates, and coded them as 1. For the predictor variables, three performance levels were the main research interests and the analyses were run twice (i.e., first analysis contained the low performance group and second included the middle performing students) as the reference groups. For the covariates, student groups who were female, economically disadvantaged, ESL, special education learners, and at-risk were considered as the reference group.

Benefits of Longitudinal HLM

To effectively investigate students' individual changes in mathematics scores influenced by STEM PBL, we employed HLM as an analytic approach (Hox, 2002; Raudenbush & Bryk, 2002). Longitudinal HLM is a multi-level analytic approach, which regards individuals as the second level and time points nested to an individual as the first level. Longitudinal HLM has several benefits. First, it enables researchers to have a larger number in their sample size than other quantitative methodologies (e.g. ANOVA, ANCOVA, and MANOVA). This is because it allows for having a different number of participants for each time point. In other words, it is not necessary for each individual to have the same number of time points in the longitudinal HLM analysis and missing data, except for explanatory variables, does not need to be excluded from the analysis (Hox, 2002). Therefore, the numbers of students were different across years.

Another benefit of longitudinal HLM was the ability to have more accurate estimates compared to other analyses. A traditional regression approach when used to analyze student level would inflate standard errors and result in an inaccurate estimation of regression coefficients (Chen et al., 2008). That is, variables (dependent) among student levels could be explained better by employing nested data within HLM (Chen et al., 2008).

Overview of Longitudinal HLM Models

Four models were designed and run to determine intra-class correlation (ICC) and the percentage of explained variance by adding more controlled covariates. The first model was designed to estimate the ICC, which is a statistical measure related to the

extent of how much individually nested groups resembled each other. In the present study, ICC indicated how strongly each individual's scores for three years were correlated. The first model equations were:

$$ACHIEVEMENT_{ti} = \pi_{0i} + e_{ti}$$

$$\pi_{0i} = \beta_{00} + r_{0i}$$

where, $ACHIEVEMENT_{ti}$ = student's (ID=i) TAKS mathematics score in the year t (2008, 2009, and 2010); π_{0i} = estimated TAKS mathematics score for individual i in the year 2008 (intercept); β_{00} = individuals' intercepts averaged across the sample; e_{ti} = random within-subjects error of prediction for individual i in the year t; and r_{0i} = random effect of individual i.

The second model was to investigate the effect of STEM PBL across the years (2008 through 2010) without any predictors and covariates. The second model equations were:

$$ACHIEVEMENT_{ti} = \pi_{0i} + \pi_{1i} \times (YEAR\text{-}2008)_{ti} + e_{ti}$$

$$\pi_{0i} = \beta_{00} + r_{0i}$$

$$\pi_{1i} = \beta_{10} + r_{1i}$$

where, π_{1i} = estimated rate of linear change in mathematics scores from 2008 to 2010; β_{10} = individuals' slopes averaged across the sample; and π_{1i} was measured with error r_{1i}.

In the third model, the students' performance levels were included to examine the effect of STEM PBL lessons on the improvement in mathematics scores by the different performance levels. Students' individual factors were not yet considered in running the analysis. The second level equations in the third model were:

$$\pi_{0i} = \beta_{00} + \beta_{01} \times (Performance_{12}) + \beta_{02} \times (Performance_{13}) + r_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} \times (Performance_{12}) + \beta_{12} \times (Performance_{13}) + r_{1i}$$

where, β_{00} = grand mean of students' scores in 2008 to 2010; β_{10} = average slope of growth in students' scores; β_{01} = mean difference between middle and low performance groups for the average intercept; β_{11} = mean difference between middle and low performance groups for the average slope; β_{02} = mean difference between high and low performance groups for the average intercept; β_{12} = mean difference between high and low performance groups for the average slope; and r = random errors after controlling the difference of performance levels.

The fourth model included students' individual factors (i.e., gender, ethnicity, economic disabilities, ESL, special education, at-risk) as covariate variables and the predictor (i.e., performance levels). The second level equations contained changes like those below:

$$\pi_{0i} = \beta_{00} + \beta_{01} \times (Gender) + \beta_{02} \times (Ethnicity) + \beta_{03} \times (EcoD) + \beta_{04} \times (ESL) +$$

$$\beta_{05} \times (SE) + \beta_{06} \times (At\text{-}Risk) + \beta_{07} \times (Performance_{12}) + \beta_{08} \times (Performance_{13}) + r_{0i}$$

$$\pi_{1i} = \beta_{11} + \beta_{11} \times (Gender) + \beta_{12} \times (Ethnicity) + \beta_{13} \times (EcoD) + \beta_{14} \times (ESL) +$$

$$\beta_{15} \times (SE) + \beta_{16} \times (At\text{-}Risk) + \beta_{17} \times (Performance_{12}) + \beta_{18} \times (Performance_{13}) + r_{1i}$$

where, EcoD = economic status; SE = special education; β_{0i} (i=1, 2, 3, 4, 5, 6, 7, and 8) = mean difference between groups (female and male, Hispanic and others, economic disabled and others, ESL and others, special education and others, at-risk and others, middle and low performance groups, and high and low performance groups, respectively) for the average intercept; and β_{1i} (i=1, 2, 3, 4, 5, 6, 7, and 8) = mean difference between

groups for the average slope. The independent variables of individual factors were controlled in this analysis to examine the pure effect of STEM PBL on student academic achievement, rather than considered them as interesting focal variables. However, conditional second level equations in the third and fourth models still enabled the researchers to examine the group differences associated with individual student factors.

After four linear models fitted the collected data, a 2LL was utilized to compare both the fixed effect and the variance component estimates and to examine which model should be selected (Raftery, 1996). 2LLs of four models were reported and smaller values of 2LL indicated the better fit models.

Results

Descriptive Summaries and Correlation Coefficients

Descriptive statistics were employed to illustrate the distribution of the participants across variables used in the study. Descriptive statistics including frequency, mean, and standard deviation were reported (see Table 5). From the descriptive statistics, it was apparent that female, economically disadvantaged, LEP, ESL, special education, non-gifted, and at-risk students performed below their counterparts, whereas performance was equal by ethnicity. In addition, student characteristics were varied across three performance levels. There were 505 students who did not meet the standard, 264 who met the standard, and 67 who had commended performance. First, the low and middle performance groups consisted of almost an even ratio of gender (male: female = 1:1.02, 1:1.13, respectively) with less male students. In the high achievement group, however, male students (n=38) outnumbered female (n=29). The percentage of Hispanic

students ranged from 50.9% to 60.2% across the three performance groups. On the other hand, low, middle, and high performance groups represented varied distributions of economic status and at-risk students. When considering economic status, more than 80% of the students in low and middle performance groups as compared to 61% of the students in the high group were economically disadvantaged. For the at-risk variable, more than 80% of students in the low performance group, 40% in the middle performance group, and less than 6% in the high performance group were at-risk. Only about 4% of the students in the low performance group were classified as special education with no students in the high and middle performance groups containing students in that category. About 9% and 3% of students in the low and middle performance groups were ESL and there were no ESL students in high performance group.

Table 5

Descriptive statistics of 2008 (Baseline scores)

Predictors		Low Achievers (N=505)	Middle Achievers (N=264)	High Achievers (N=67)	Total
Raw Score Range		0~30	31~44	45~52	
		N Mean (SD)			
Gender	Male	250 18.61 (8.909)	124 37.10 (4.204)	38 46.92 (1.683)	412 26.79 (12.802)
	Female	255 19.47 (8.859)	140 36.66 (3.662)	29 46.90 (1.633)	424 27.02 (11.995)
Ethnicity	Hispanic	257 18.81 (9.329)	159 36.74 (3.959)	37 46.86 (1.316)	453 27.39 (12.593)
	Non-Hispanic	248 19.29 (8.413)	105 37.07 (3.881)	30 46.97 (2.008)	383 26.33 (12.142)
Economic Status	Economic Disables (ED)	450 19.20 (8.664)	218 36.57 (3.861)	41 46.78 (1.388)	709 26.14 (11.879)
	Non-ED	55 17.80 (10.533)	46 38.26 (3.963)	26 47.12 (2.007)	127 31.21 (14.241)
ESL	ESL	43 12.74 (11.215)	8 34.75 (3.655)	0 —	51 16.20 (13.147)
	Non-ESL	462 19.63 (8.415)	256 36.93 (3.921)	67 46.91 (1.649)	785 27.60 (12.025)
Special Education (SE)	SE	19 13.47 (6.979)	0 —	0 —	19 13.47 (6.979)
	Non-SE	486 19.26 (8.887)	264 36.87 (3.924)	67 46.91 (1.649)	817 27.22 (12.320)
At-Risk (AR)	AR	407 18.50 (8.753)	107 34.87 (3.066)	4 46.25 (1.258)	518 22.09 (10.515)
	Non-AR	98 21.32 (9.116)	157 38.23 (3.869)	63 46.95 (1.670)	318 34.75 (11.168)

Table 6

Bivariate correlations for student-level variables

Correlations	Gender	Grade	Ethnicity	Economic Disadvantage	ESL	Special Education	At-Risk	Achievement
Gender	1	.023	-.080**	-.025	-.029	-.046*	-.013	-.003
Grade	—	1	.033	.013	.047*	.006	.054*	.378**
Ethnicity		—	1	-.132**	.112**	-.014	-.205**	.057*
Economic Disadvantage			—	1	.046*	.028	.212**	-.145**
ESL				—	1	-.038	.168**	-.139**
Special Education					—	1	.106**	-.147**
At-Risk						—	1	-.449**
Achievement							—	1
Skewness	*-.029*	*.363*	*.106*	*-1.843*	*3.693*	*6.188*	*-.664*	*-.413*
Kurtosis	*-2.001*	*-1.431*	*-.235*	*1.400*	*11.653*	*36.326*	*-1.560*	*-.046*

Note. Ethnicity was coded as 1 for Hispanic and 0 for others (i.e. African American, White (not of Hispanic Origin), and Asian or Pacific Islanders). **$P<0.01$, *$P<0.05$.

Bivariate correlations among the variables were calculated to examine to what extent, student individual factors were related (Table 6). The results from the correlation analysis demonstrated that gender was not correlated with students' performance scores ($r = -.003$, $p > .05$). This illustrated that male students' scores were not as likely to differ from female students' scores. Student scores were correlated positively with ethnicity, whereas negatively with economically disadvantage, ESL, special education, and at-risk characteristics. Being Hispanic correlated slightly with higher scores, as compared to non-Hispanic. Students who were classified as economically disadvantaged, ESL, special education, and at-risk were correlated to lower scores than students not classified in these categories.

HLM Analyses of Students' Scores and Individual Factors

The longitudinal data including students' mathematics scores and individual factors were analyzed using HLM following the method described by Hox (2002) and using HLM 7 software. Treating students' repeated scores for three years as nested within individual students allowed for longitudinal analyses of the given data and four kinds of HLM models, and permitted assess to whether student individual factors affected mathematics test scores. The first model was the unconditional model in which only outcome variable was modeled to determine the variation within cases.

Unconditional Model: Model 1

The employed unconditional growth model included only an outcome variable without any predictors and examined the extent to which students' initial scores statistically varied over time. The grand mean was 29.23 and the estimated within-

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student variance (σ^2) and between-student variance (τ_{00}) were 57.93 and 120.05,

respectively. The unconditional model did not include any predictors in level-1 and

level-2 equations, and allowed us to examine how much percentage of the total variance

was resulted from STEM PBL for three years and how much was due to student

individual factors. The ICC (Raudenbush & Bryk, 2002) from the first model was

calculated by the formula, $\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ and 0.675. In other words, 67.5% of the

total variance in mathematics scores could be explained by individual student factors and

33.5% was caused by involvement in STEM PBLs.

The Final Model: Model 4

The fourth model contained predictors (i.e., performance$_{12}$ and performance$_{13}$)

and covariate variables (i.e., gender, ethnicity, economic status, ESL, special education,

and at-risk) in level-2, including the interaction effects of time controlling for any impact

of student individual factors. The HLM results for the fourth model were summarized in

Table 7 showing two effects: main and interaction effects. First, the estimates of main

effects indicated how much each predictor and covariate variable influenced students'

initial score in 2008 (i.e., intercept). The main effects of time ($\beta_{10} = 5.66$, $t = 5.949$; $p <$

0.001), performance$_{12}$ ($\beta_{07} = 16.046$, $t = 27.554$; $p < 0.001$), performance$_{13}$ ($\beta_{08} =$

25.403, $t = 25.362$; $p < 0.001$), ESL, special education, and at-risk were statistically

significant. Moreover, the interaction effects of ethnicity, economic status,

performance$_{12}$ (i.e. the difference between middle and low level of performance groups),

and performance$_{13}$ with time variable were statistically significant.

Table 7

Estimates, variances, and effect sizes

Effect	Estimate	Std. Error	*t / Wald Z*	Effect Size (Hedge's g)
Fixed effect				
Intercept	20.646	0.839	24.608	4.890
Time	5.656*	0.951	5.494	1.340
Gender	-0.128	0.488	-0.262	0.030
Ethnicity	0.203	0.512	0.397	0.048
Economic Status	0.890	0.698	1.276	0.211
ESL	-5.473*	1.054	-5.190	1.296
Special Education	-6.267*	1.671	-3.751	1.484
At-Risk	-2.081*	0.575	-3.618	0.493
$Proficiency_{12}$	16.046*	0.582	27.554	3.800
$Proficiency_{13}$	25.403*	1.001	25.362	6.016
Time××Gender	0.458	0.505	0.907	0.108
Time×Ethnicity	1.159*	0.541	2.142	0.275
Time×Economic Status	-2.165*	0.796	-2.719	0.513
Time×ESL	1.729	1.115	1.551	0.410
Time×Special Education	1.839	2.231	0.824	0.436
Time×At-Risk	0.769	0.640	1.200	0.182
Time×$Proficiency_{12}$	-2.585*	0.590	-4.378	0.613
Time×$Proficiency_{13}$	-2.850*	0.981	-2.906	0.675
Random effect variance				
σ^2	33.938	2.763	12.285	—
τ_{00}	17.826	3.576	4.985	—
τ_{11}	12.772	2.827	4.518	—

Note. **$P<0.01$, *$P<0.05$.

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To determine the different growth rate between middle and high performance groups, another analysis was conducted using the middle performance group as a reference group. The estimated values of two interaction effects, time×performance$_{21}$ (i.e. the difference between high and low levels of performance groups) and time×performance$_{23}$, were 2.584 ($t = 4.378$; $p < 0.001$) and -0.265 ($t = -0.293$; $p = 0.769$). In other words, the three estimates of all three performance groups were positive; however, the interaction effect between time and performance$_{23}$ was not a statistically significant predictor of student mathematics scores on TAKS. That is, the middle and high performance groups demonstrated a statistically significant lower growth rate than the low level performance group during three years, whereas the growth rate of the high performance group did not differ from the middle performance group (see Figure 5).
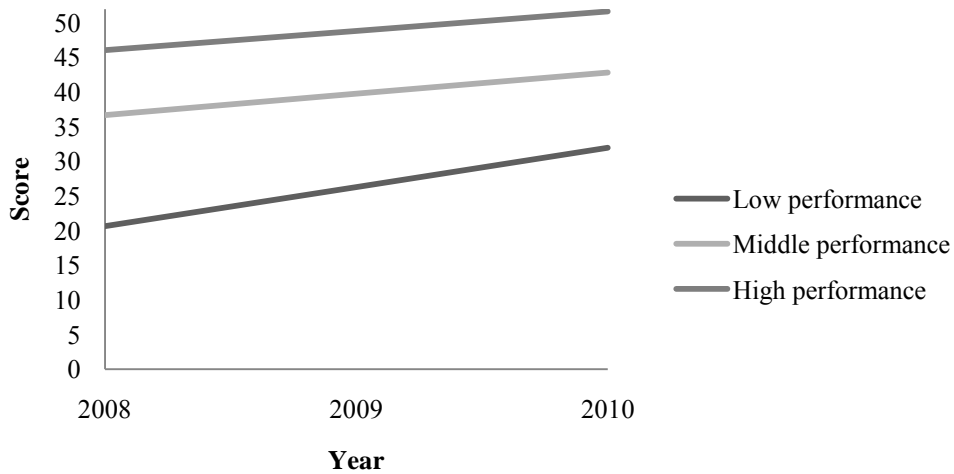

Figure 5. Growth trajectory of diverse proficiency groups for three years.

Time-variant covariates presented varied estimates and significant *p*-values (see Table 7). Among the main effects, the predictor variable (i.e., performance level), and three covariates (i.e., ESL, special education, and at-risk variables) were examined and determined to be statistically significant, whereas, gender, ethnicity, economic status were not. That is, student's individual factors such as performance level, ESL, special education, and at-risk, affected the initial scores in 2008 (i.e., intercepts of the three trajectory lines in Figure 5). Other than the interaction effects of time with performance, interaction effects of time with gender, ethnicity, economic disability, LEP, ESL, special education, gifted, and at-risk were examined to determine whether they were significant predictors of student achievement in mathematics. The interaction effects of time with ethnicity ($\beta_{12} = 1.159$, $t = 2.142$; $p = 0.033$) and economic status ($\beta_{13} = -2.165$, $t = -2.719$; $p = 0.007$) were statistically significant. In other words, these two interaction effects significantly impacted the slope of growth trajectory lines in Figure 5.

Additionally, standardized effect sizes were calculated by the following equation (Hedges, 2007):

$$\delta_B = \frac{\beta_\bullet - \beta_\bullet^*}{\sigma_B} = \frac{\beta}{\sqrt{\tau_{00}}}$$

For example, a significant performance level of fixed effect between low and middle groups was observed ($\beta_{07} = 16.046$, $p < 0.05$) where the mean score of the middle group ($\beta_{middle\ group} = 36.692$) was higher than the mean score of the low group ($\beta_{middle\ group} = 20.646$). The standardized effect size of performance levels between low and middle groups was 3.8. Among the interaction effects, the growth rate interaction effect of

ethnicity was significant ($\beta_{12} = 1.159$, $p < 0.05$) and the growth rate of Hispanic students ($\beta_{Hispanic} = 6.815$) was higher than others ($\beta_{non\text{-}Hispanic} = 5.656$). The standardized effect size of the ethnicity interaction effect was 0.275. Similarly, other effect sizes were calculated and interpreted (see Table 7).

In summary, the results showed that students' achievement in mathematics was dependent on multiple factors as well as STEM PBL instruction. Students who were high and middle level performers in mathematics demonstrated almost no differences in terms of growth rate of mathematics scores over three years. In addition, low performing groups of students showed significantly higher growth rates than the high and middle performing groups of students. That is, the enactment of STEM PBLs in classrooms was more likely to demonstrate positive impacts on students in low performance groups, rather than in the high and middle performing groups.

Auxiliary Statistics

To obtain information on the longitudinal HLM models, two auxiliary statistics, variance explained and 2LL were reported (Table 8). The _variance explained' was computed for models 2 through 4 to estimate how much within- and between-student variances (τ_{00} and σ^2) of each model were further explained as more predictors and covariate variables were added (Raudenbush & Bryk, 2002). The proportions of variance explained of σ^2 and τ_{00} were calculated at level-1 and level-2 respectively. Another auxiliary statistics, 2LL, was calculated to select the best-fit model for the collected data. The 2LL value of the fourth model was smallest, which indicated the best-fit model.

Table 8

Percent of variance explained at level-1 and level-2

Model	Added Variables	Variance Explained at Level-1 (σ^2)	Variance Explained at Level-2 (τ_{00})	2 Restricted Log Likelihood (2LL)
Model 1	—	—	—	12930.66
Model 2	Time	44.78%	-1.27%	12596.76
Model 3	Model 2 + Proficiency levels	42.13%	82.16%	11684.81
Model 4	Centered time variable + Proficiency levels + Gender, Ethnicity, Economic Status, ESL, Special Education, At-Risk	41.41%	85.15%	11600.91

Discussion

Developing effective STEM education has been regarded as one of the most significant challenges facing educators along with improvement in student performance in the areas of science and mathematics along with engineering. However, the effectiveness of implementing STEM PBL in terms of improving students' scores in mathematics and science has not demonstrated as much improvement as was previously expected. This study provides an evaluation of implementing STEM PBL activities in schools to determine improvements in students' academic achievement in mathematics. These findings should help teachers and educators rethink about how students of varied performance levels benefit from engaging in STEM BPL activities, and guide them in restructuring their instructional strategies to engage diverse learners in their classrooms.

First, this study contributes to the scholarly significance of understanding the effect of STEM PBL activities on student achievement. We found a positive growth rate in students' academic achievement in mathematics while STEM PBLs were implemented at the high school level, similar to Baran and Maskan (2010) who reported positive effect sizes when implementing STEM PBL activities at the university level. Results of the present study supports differentiated education and accelerated learning, which tend to provide varied learning environments for students who are at different performance levels. Students in high, middle, and low performing groups in this study demonstrated varied growth rates, which indicates that each performance group requires a different learning environment. In other words, components of STEM PBLs such as group projects, collaboration, ill-defined tasks, and student-centered environments inter-

relationally function with each other, and some components of STEM PBL are more appropriate for specific performance levels of students (Abraham et al., 2011; Cheng et al., 2008; Kajamies et al., 2010). Therefore, implementing STEM PBLs in schools can have diverse impacts on student achievement and attitude according to their performance levels.

Conversely, results of the present study differed from Yoon (2009)'s research concluding that high achievers received more positive impact with student-directed and self-regulated learning environments. A student centered learning environment is the main feature of a STEM PBL classroom and we found that the low performing group of students improved at a higher level than the high and middle performing groups when looking at student achievement on mathematics under a STEM PBL learning environment.

The results of the present study support the findings that individual student factors influence student academic achievement. As Ma and Klinger (2000) insisted, SES was a critical predictor of students' mathematics scores. According to the results of this study, a student's economic status was also found to be an important factor in improving mathematics test scores through STEM PBL experiences. The estimate of the interaction effect of time and economic status was negative indicating that students who were of low economic status (i.e., students eligible for the free meal or reduced meal) showed a negative growth achievement rate while engaging in STEM PBL over the three years. The implication of the relationship between student's SES and academic achievement should be regarded as a serious problem because a student's economic

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status was a critical factor influencing a student's academic achievement in mathematics, even though there was a not statistically significant difference in the initial year. In other words, low economic status was not a barrier for students in the first year of this study; however, students in the low economic status group ultimately received negative impacts from their engagement in STEM PBLs.

When examining the factor of student's ethnicity, there have been debates regarding the impact of ethnicity on students' academic achievement with the results varying by the research design and participants' characteristics (Capraro, 2001; Ma & Klinger, 2000). This study contained mostly Hispanic student participants, and showed a significant difference compared to the other ethnic groups. Hispanic students had a higher growth rate on mathematics tests for three years during the implementation of STEM PBL activities. That is, results from this study imply that STEM PBL activities were more likely to be appropriate instruction for Hispanic students rather than other student groups. The participants' demographic feature may be a limitation of this study, because it was hard to extend the results of this study to a comparison of Hispanic students with African America, White or Asian students on mathematics performance, separately.

Lastly, this study likely represents one of the first studies utilizing advanced research analysis. Whereas most of studies utilized *t*-test, correlation, ANOVA, and ANCOVA (Baran & Maskan, 2010; Chang & Lee, 2010; Domínguez & Jaime, 2010; Lou et al., 2011; Kaldi et al., 2011; van Rooij, 2009), the present study employed longitudinal HLM, with diverse student factors examining the effect of implementing

STEM PBLs on student achievement. By using longitudinal HLM, we investigated the trajectory of improvement in students' academic achievement, not just a simple comparison at a specific point in time. In addition, the estimates of fixed and random effects in this study are more accurate than other studies' results because we controlled for more variables by using longitudinal data.

For further study, we would like to suggest that researchers clarify the reasons for the results obtained in this study. That is, they should investigate why students of different performance levels showed different growth rates and how student individual factors functioned with diverse components of STEM PBL. For example, the low performing group in this study showed more positive impacts from group collaborations while engaging in STEM PBL classroom activities similar to Rivard (2004)'s study. However, it was impossible to determine why the positive impact on low achievers resulted from the heterogeneous grouping in STEM PBLs (Chen et al., 2008). The data in this study were limited to disclose the effectiveness of STEM PBL, thus not enough to investigate how and why STEM PBLs positively influenced student achievement.

CHAPTER V

SUMMARY AND CONCLUSIONS

The present dissertation includes three integrated manuscripts focusing on the effects of STEM PBL in schools. These three articles consistently describe the reality of STEM PBL in schools with teachers and students. The first article illustrates the impact of PD on teacher's conceptions and implementation of STEM PBL. Both quantitative and qualitative approaches disclose the effects of PDs on teacher's fidelity in enacting STEM PBL, as well as the existing gap between teacher's concepts and implementation of STEM PBL. The second and third articles investigate the impact of teacher participation in STEM PBL PD on high school students' improvement in mathematics achievement. The second article examines the effect of STEM PBL on Hispanic and at-risk students by comparing student mathematics achievement between STEM PBL and non-STEM PBL schools. The employed latent growth model shows the positive effect of STEM PBL on Hispanic student's growth rate of mathematics achievement but not on at-risk student's growth rate of mathematics achievement. The third article examines how STEM PBL shows different effects on high, middle, and low achievers by using HLM.

The present dissertation demonstrates how STEM PBL influences student mathematics achievement longitudinally by providing the sustained PD for in-service teachers in high schools. Without question, students learn better from more qualified teachers. In other words, teacher quality and fidelity in implementing STEM PBL is

closely related to student improvement in academic achievement. The purpose of PD for inservice teachers is to improve their content and pedagogical knowledge, which has a positive influence on student academic achievement. This dissertation illustrates the sequence from the sustained PDs on STEM PBL to changes in teacher's concepts and enactments of STEM PBL, and from teacher's improved understanding of STEM PBL to students' improvement in mathematics achievement. Therefore, the findings of this dissertation are regarded as an evaluation of PDs.

PD for in-service teachers should be sustained to guarantee a teacher's fidelity to the teaching pedagogy. In addition, educators providing PDs have to realize that teachers' concepts of STEM PBL may be different from their enactments in classrooms. Moreover, teachers represent similar and/or diverse concepts and implementations of STEM PBL after attending PDs. The findings of this dissertation imply that only sustained PD guarantees a teacher's fidelity in implementing the reformed instructional approach. Once PD is terminated, a teacher's fidelity may not be retained further. Therefore, continuous and sustained PDs plus administrative support are necessary to keep the retention of the PD's effect of the teachers' STEM PBL implementation in classrooms. Additionally, organizing professional learning communities in schools or online learning communities may be utilized to increase the effect of PD and keep it ongoing until it becomes an instructional habit.

Overall teacher participation in PD through this study showed a positive influence on student improvement in mathematics achievement. However, the effect of STEM PBL on student academic achievement depended on individual factors such as

gender, ethnicity, language proficiency, economic status, educational risk, and mathematics performance. Some students showed a higher growth rate of mathematics academic achievement across the years than others in spite of a same teacher's STEM PBL activities. As revealed in previous studies (Abraham et al., 2011; Capraro, 2001; Capraro et al., 2009; Chen et al., 2008; Kajamies et al., 2010), the findings of this dissertation illuminate student individual situations, especially ethnicity and academic performance, are key factors in determining their academic achievement.

Implementation of STEM PBL in classrooms with Hispanic students enabled this population to increase their academic achievement in mathematics. Hispanic students' improvement in mathematics achievement through STEM PBL activities is remarkable compared to other ethnic groups. STEM PBL PD encouraged teachers to include more culturally diverse contexts and supported team collaborations, which required more conversations among peers in STEM PBL classrooms than traditional classrooms. While communicating with others, Hispanic students may have had more opportunities to improve their English language proficiency, especially their mathematical vocabulary. This dissertation does not undertake more detailed processes, which may explain how STEM PBL components effect Hispanic student mathematics achievement. However, the findings from this dissertation advocate for STEM PBL for Hispanic students, which should be emphasized with our subsequent STEM PBL PD trainings for teachers. Teachers need to understand Hispanic students' characteristics, which cause their low academic achievement. Moreover, they also should realize that STEM PBL has effective

components especially for Hispanic as a result of changing their teaching pedagogies through STEM PBL PDs.

High, middle, and low achievers in a STEM PBL classroom showed various improvements in mathematics achievement. According to the findings of this dissertation, STEM PBL activities more positively influenced low achievers than high and middle achievers. STEM PBL normally includes group collaboration. The low achievers may have more chances to recover deficits of mathematical content knowledge in a group work, when the group consisted of diverse achievers. This finding was similar to those found by Chen et al., 2008. Moreover, the positive effect of STEM PBL on low achievers is consistent with the positive effect on Hispanic students, in terms that more Hispanic students are generally designated as low achievers. When examining how the gap between high and low achievers decreases, STEM PBL activities should deserve more attention from teachers, educators, and policy makers. However, the refinement of STEM PBL for high and middle achievers should not be ignored.

The research methodologies employed in this dissertation allowed for illustrating how STEM PBL PD for teachers effected student academic achievement. The mixed method employed enabled us to look at the changes in teacher concepts and enactments of STEM PBL qualitatively, which was also supported by quantitative findings. Moreover, the latent growth modeling and HLM provided more relaxed assumptions in analyzing the limited data with some missing cases. In other words, the advanced methodological approaches allowed for analysis of the data, which necessarily included missing data. Hispanic, at-risk, and low achievement level students are deemed likely to

transfer to other schools or drop out of school in their later school years. That is, these types of students were more likely to be the kind of students who would cause researchers to encounter missing data, when analyzing repeated measures across years. Therefore, this dissertation serves as a good example for the further studies with the data set having similar methodological issues.

The dissertation explains how STEM PBL PD effected teachers' understanding and implementation of STEM PBL and student improvement in mathematics achievement. However, further study is necessary to demonstrate the connection between the improvement of teachers' pedagogical knowledge and students' content knowledge. In other words, further studies need to examine teacher's quality and fidelity in enacting STEM PBL when analyzing student academic achievement data. Moreover, further research may be proposed to examine the additional issues relevant to STEM education and STEM PBL. For example, student academic achievement is deeply related to retention and drop out rate. Therefore, further research investigating the effect of STEM PBL on student retention and completion rate may be proposed.

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APPENDIX A

PROPOSED ARTICLES AND JOURNALS

Proposed Articles	Proposed Journal #1	Proposed Journal #2
In-service Teachers' Implementation of and Understanding from PBL in STEM Fields	*Teaching and Teacher Education* • Acceptance rate: N/A • Impact factor: 1.124 5-Year impact factor: 1.546 • Editor in chief/Co-editors: J. Clandinin, M. L. Hamilton • Publisher: Elsevier • Type of review: Peer Review • Manuscript length: 5,000-9,000 words	*Teachers and Teaching: Theory and Practice* • Acceptance rate: N/A • Impact and ranking (SJR/SNIP): 0.033/1.398 • Editor in chief/Co-editors: Christopher Day • Publisher: Routledge • Type of review: Peer Review • Manuscript length: 4,000-6,000 words
The Effect of STEM PBL on Hispanic and At-risk Student Mathematics Achievement	*Education and Urban Society* • Acceptance rate: N/A • Impact factor: 0.379 • Editor in chief/Co-editors: Chales J. Russo • Publisher: Sage • Type of review: Peer Review • Manuscript length: 25 pages	*Educational Studies in Mathematics* • Acceptance rate: 25% • Impact and ranking (SJR/SNIP): 0.032/1.942 • Editor in chief/Associate editors: Norma Presmeg • Publisher: Springer • Type of review: Peer Review • Manuscript length: 16-20 pages
How STEM PBL Differently Affects on High, Middle and Low Achievers	*International Journal of Science and Mathematics Education* • Acceptance rate: N/A • Impact factor: 0.529 • Editor in chief: Fou-Lai Lin • Publisher: Springer • Type of review: Peer Review • Manuscript length: 30 pages	*Journal for Research in Mathematics Education* • Acceptance rate: 6.8% in 2009 • Impact and ranking (SJR/SNIP): 0.039/2.359 • Editor in chief/Co-editors: Cynthia Langrall • Publisher: NCTM • Type of review: Peer Review • Manuscript length: 35~40 pages

APPENDIX B

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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)

	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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)
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 (Non Applicable)

APPENDIX C

LESSON PLAN SAMPLE

TITLE: —Do you see it? Exploring Quadratics"

WELL-DEFINED OUTCOME: The student will make a connection between quadratic formula and real world.

INTRODUCTION/BACKGROUND:

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.

CONNECTIONS/OBJECTIVES/TEKS

Mathematics:

Foundations for Functions

TEKS The student formulates systems of equations and inequalities from problem situations, uses a variety of methods to solve them, and analyzes the solutions in terms of the situations.

A). analyze situations and formulate systems of equations in two or more unknowns or inequalities in two unknowns to solve problems

B). use algebraic methods, graphs, tables, or matrices, to solve systems of equations or inequalities

C). interpret and determine the reasonableness of solutions to systems of equations or inequalities for given contexts

MATERIALS

Manilla folder for each group

Flip Video

Transparencies

Co-ordinate plane on transparencies

Posters boards

COW carts

Calculators

Computers (COW)/Access to internet for research

Access to printer

Visa Vi markers

Markers, pens, pencils, colored pencils

Rulers

TIMELINE (4 days)

Day 1 – Introduction and discussion, Students explore Quadratic formula through rap,

song, poem, play, or poster

Day 2 – Students continue exploring and get ready to present their understanding

Day 3 – Student presentation

Day 4 – Students research about a real-world example of quadratics

Day 5 – Students prepare their presentations by calculating the quadratic in the real-world example chosen.

Day 6 – Students presentations

Engage – Assign the students into groups of 4. Give the students a copy of the scenario and students handouts and read it aloud to them. Have students in each group assigned to a task, Student #1 will get the computer. Student #2 gets the calculator for each group member. Student #3 gets the pens/pencils and transparency. Student #4 gets the poster board and any other materials that the group would need.

Explore— Each group makes a presentation over the quadratic function and uses the internet to find a picture of a quadratic function in architecture.

Explain— Prepare the presentation with details of quadratics. Also analyze the quadratic picture and finding the quadratic regression equation.

Evaluate— Assess student performance through the skit/rap/poster/poem and assess the regression poster and the data obtained.

Extend— The project is extended by actually giving students a quadratic equation and then design a building using that quadratic!!!

RUBRIC

_____ Project is related to quadratic equations (**15 points**)
_____ Project is mathematically correct (**20 points**)
_____ Project neatly written down with names in the back and on-time (**10 points**)
_____ Typed/neatly written or drawn or sang for the class to see/hear (**10 points**)
_____ Presentation was organized (**10 points**)

_____ Has all group members' involved in the project (**15 points**)

_____ Project completed on time (**5 points**)

_____ WOW factor – Be creative with your design and artwork (**15 points**)

Quadratic Equation Project – Part 1

Directions

Choose any one the following projects to do.

The project must contain something directly related to quadratics. Every member of the group needs to participate **(they are participation points!!!)**. Yes, this means *each person is to participate and present something.*

You can work in groups no more than 4 students. The group will write out whatever they choose neatly and submit with their names on the back

Projects

1. You may create a story about quadratic equations or solving them
2. You may make a rap about quadratics or quadratic formula
3. You may make a poster about quadratic equations, quadratic formula, ways of solving and example of each type
4. You may make a poem and recite it about any part of quadratics
5. You may do a role playing about quadratics and solving the equations.

RUBRIC

_____ Project is related to quadratic equations (**15 points**)

_____ Project is mathematically correct (**20 points**)

_____ Project neatly written down with names in the back and on-time (**10 points**)

_____ Typed/neatly written or drawn or sang for the class to see/hear (**10 points**)

_____ Presentation was organized (**10 points**)

_____ Has all group members' involved in the project (**15 points**)

_____ Project completed on time (**5 points**)

_____ WOW factor – Be creative with your design and artwork (**15 points**)

Quadratic Equation Project – Part 2

Directions

The second part of this project will consist of using the computer and the Internet to find Quadratics in architecture. Each group of 4 will split into groups of only 2 students. Together you will find an example of a Quadratic function from the internet. Once you have found one, you are to print out the picture and begin to find the regression equation of that Quadratic graph. Use a transparency to begin to plot points on a coordinate plane. After finding those points, use the Regression handout to find the regression equation. Organize this all on a poster board, detailing your picture, graph and your process.

RUBRIC

_____ Project is related to quadratic equations (**15 points**)

_____ Project is mathematically correct (**20 points**)

_____ Poster is organized and understandable (**20 points)**

_____ Creative poster and picture (**20 points)**

_____ Has all group members' involved in the project (**15 points**)

_____ Project completed on time (**10 points**)

"Do You See It? - Exploring Quadratics"

HOW TO: Graph a Scatterplot and Quadratic Regression with the TI-Nspire

Follow these instructions to create a scatterplot on the TI-Nspire.

6. From the HOME screen, create a New Document by pressing 1 or moving to New Document

7. If it asks you to save the 'Unsaved Document' press No. Then Add a Lists & Spreadsheet page.

8. Create a Spreadsheet to look *exactly* like this. Leave the shaded portion blank.

	A domain	B range	C	D
*				
1				
2				
3				
4				
5				

A) Once you have compiled your data, input the corresponding domain and ranges.

B) After both domain and range columns have been filled, press the 'ctrl' button and then the 'doc V' button. (The 'doc V' button is below the HOME button.) Create a new 'Data and Statistics' page.

C) At this point you will see points in random places on the screen. Move your cursor to the bottom portion of the screen where it says ―click to add variable" and choose your 'x' value to be domain. After you select the 'x' value, move to the left hand side of the screen and choose your 'y' value to be range. You will notice that the points line up nice and neat in the graph.

D) **REGRESSION**: Now to find the quadratic regression equation of that graph, press the MENU button and then click Analyze, followed by Regression followed by #4 Show Quadratic. That will give the quadratic regression equation.