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AN EXAMINATION OF SECONDARY MATHEMATICS TEACHERS' TPACK

DEVELOPMENT THROUGH PARTICIPATION IN A TECHNOLOGY-BASED LESSON

STUDY

A Dissertation
presented in partial fulfillment of requirements
for the degree of Doctor of Philosophy
in the School of Education
The University of Mississippi

by

JULIE W. RIALES

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ABSTRACT

This qualitative research study used a layered case study (Patton, 2002) to examine the technological, pedagogical, and content knowledge (TPACK) of a group of inservice secondary mathematics teachers as they participated in a technology-based lesson study. Using the TPACK Development Model (Niess, 2009) as a lens, this dissertation examines interactions of the group members during lesson study meetings as well as individual case studies of four of the six participants.

Data were gathered from initial surveys, initial and post-interviews, initial and post-classroom observations, writing prompts, and transcriptions of lesson study group meetings. Data were analyzed to determine the TPACK development levels for different themes of the model at different stages during the lesson study process. Thick descriptions are provided of actions and quotes from the participants that exemplified various TPACK development levels.

Findings indicated that the design and purpose of technology-based lesson study provided participants opportunities to practice actions from the higher levels of the TPACK Development Model during the lesson study. Based on classroom observations, half of the participants demonstrated practices that indicated increases in TPACK development levels following the lesson study. Those participants with less experience with technology in their educational backgrounds demonstrated greater positive changes. Participant responses to interview questions and writing prompts indicated that experiencing learning with technology and observing students' thinking served to prompt changes in their own practices.

DEDICATION

This dissertation is dedicated to all of my friends and family who supported me in this effort. In particular, I thank my husband, Kevin Riales, and our two sons, Brian and Dylan Riales, for their love, support, and patience.

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First and foremost, I thank God for giving me the mental fortitude to advance this far in my education and career, for being my source of strength, and for providing the needs for my family. Without Him, I am nothing!

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Very special thanks to Dr. Angela Barlow for her guidance in my academic decisions and throughout my graduate studies and dissertation process. I appreciate her example, her partnership in research opportunities, and her mentorship. Serving as chair of my dissertation committee, her dedication and support was outstanding! The sacrifices she made of her personal time at night and during spring break will not be forgotten. I will "pay it forward."

Lastly, thanks to others who helped in this dissertation process. Thanks to Dr. Carol Livingston, Dr. Amy Wells-Dolan, and Dr. Stacie Pettit for serving on my dissertation committee. Their reviews and suggestions were beneficial in forming this final work. Thanks to

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CHAPTER I: INTRODUCTION

Introduction

From the First International Mathematics Study conducted in the 1960s to the more recent 2007 Trends in Mathematics and Science Study (TIMSS), average mathematics achievement scores of students from the United States (U.S.) have lagged behind average scores of students from other countries, such as Chinese Taipei, Hong Kong, Japan, Singapore, and Korea (Medrich & Griffith, 1992; Provasnik, Gonzales, & Miller, 2009). Despite the recent gains in average scores of U.S. students on the TIMSS which have advanced the average scores of U.S. fourth- and eighth-grade students ahead of average scores of students of many other countries, students in Asian countries have consistently and significantly outperformed U.S. students on these assessments. Additionally, the 2006 Program for International Student Assessment (PISA) ranked 15-year-old U.S. students in the bottom 25% of same-age students from countries in the Organization for Economic Cooperation and Development (OECD). Furthermore, the 2006 PISA revealed that U.S. students are not as successful at applying mathematics knowledge to real-world scenarios as their peers in most other OECD countries (Provasnik et al., 2009). This poor performance of U.S. students has led mathematics educators to question the instructional practices of U.S. teachers.

Recognizing the need to examine instructional practices, TIMSS sought to explore the differences in practices in the mathematics classrooms of the U.S. and those countries whose students consistently outperformed U.S. students. During the TIMSS video study that began in

1993, researchers studied video-taped lessons of 231 eighth-grade mathematics classrooms: 100 in Germany, 50 in Japan, and 81 in the U.S. From these video studies, distinct differences were documented concerning the interactions of teachers and their students in eighth-grade mathematics classrooms of the U.S. and Japan (Stigler & Hiebert, 1999).

In the Japanese lessons, students were more actively engaged in solving problems, thinking critically, and making connections within and communicating about mathematics. While the Japanese teacher did not play a major role during the lesson, he/she had carefully orchestrated the design of the lesson to allow for student exploration, discovery, and discussion of mathematics (Stigler & Hiebert, 1999). In their analysis of the videos in the study, Stigler and Hiebert (1999) assigned the motto "structured problem-solving" (p. 27) to describe Japanese lessons.

In contrast, the lessons from the U.S. received the motto "learning terms and practicing procedures" (Stigler & Hiebert, 1999, p. 27). In these lessons, the students did not engage in higher-level thinking or make mathematical connections. The teacher defined terms, gave examples of procedures to be carried out, observed students' work, demonstrated solutions to problems with which students struggled, reviewed that day's procedures, and assigned homework on problems like those worked in class. Students were not given the opportunity to explore solution methods or to communicate mathematically.

Call for Reform in Mathematics Education

Professional organizations of mathematics educators promoted reform in mathematics education even before the TIMSS video study revealed the major differences in the way that U.S. and Japanese teachers conducted their mathematics lessons. The National Council of Teachers of

Mathematics (NCTM) published *Curriculum and Evaluation Standards for School Mathematics* in 1989. This document encouraged helping students develop mathematical power with a broad range of topics in mathematics to be investigated through the integration of problem solving, communicating mathematically, making connections with real-world contexts and among mathematics topics, and reasoning through mathematics. Technology use was also promoted for all grade levels as a means for exploring mathematics and focusing on problem solving in real contexts rather than on tedious computations (NCTM, 1989). The *Professional Standards for Teaching Mathematics*, released by NCTM in 1991, served as a companion to the 1989 document, giving guidance and descriptions of the teaching and learning that would be required to accomplish the goals of the *Curriculum and Evaluation Standards* (NCTM, 1991).

Despite the widespread knowledge of the standards promoted by NCTM held by eighth-grade teachers involved in the TIMSS video study, lessons from the U.S. eighth-grade classrooms, for the most part, did not demonstrate these standards in action. Some U.S. teachers believed that they were implementing the standards, but their attempt at implementation was superficial, changing only features of the lesson and not their overall approach to teaching. The lessons of Japanese teachers, on the other hand, illustrated the standards much more effectively than the U.S. lessons (Stigler & Hiebert, 1999).

In 2000, NCTM made another effort to draw attention to the need for educational reform by releasing *Principles and Standards for School Mathematics (PSSM)*. This document described a vision for mathematics through the integration of the classroom-related portions of its earlier *Standards* documents in organized grade bands. Detailed content curriculum standards were given for each grade band along with process standards that described how the students should

be learning the content. The processes were the same as in the 1989 document, namely problem solving, communicating mathematically, making connections with real-world contexts and among mathematics topics, and reasoning through mathematics, with the addition of using multiple representations of ideas to expand mathematical thinking. The document also introduced six principles, i.e. equity, curriculum, teaching, learning, assessment, and technology, to serve as guides for moving toward quality mathematics education for all students (NCTM, 2000).

Technology in Mathematics Education Reform

The technology principle in *PSSM* stated: *"*Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM, 2000, p. 24). The intent of the technology use was to increase students' understandings through investigations, gaining access to mathematics that might not be available otherwise. The capabilities of the technology would allow exploring graphs, analyzing data, and changing parameters that would be time-consuming and tedious by hand. Students would be able to connect different branches of mathematics through different representations more easily managed through the technology. Students, even those with special needs, would have greater access to tackle real-life problems with complex computations (NCTM, 2000).

The technology principle further indicated that students' use of technology should not replace the role of teachers. In fact the decisions made by teachers play a major role in the effectiveness of the technology use. In the ideal classroom described in *PSSM*, every student would have access to technology to enhance his mathematics learning through the guidance of a competent teacher (NCTM, 2000).

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Other organizations have also embraced technology as a vital tool for learning. In 2000 the International Society for Technology and Education (ISTE) released the *National Education Technology Standards for Students* (*NETS-S*) to bring to teachers' attention the skills their students would need in an increasingly technological society. *NETS-S* was divided into grade bands, similar to NCTM's *PSSM,* with performance standards that students should have the opportunity to demonstrate while in those grades. The *NETS-S* contained six categories: basic operations and concepts; social, ethical, and human issues; technology productivity tools; technology communication tools; technology research tools; and technology problem-solving and decision-making tools (ISTE, 2000). Recognizing that *NETS-S* required teachers to acquire a different knowledge than they were accustomed to, in 2002 ISTE released the *National Educational Technology Standards for Teachers* (*NETS-T*). Despite these standards published in a constantly changing technological society, few changes were recognizable in the classrooms. ISTE revised *NETS-S* and *NETS-T* in 2007 and 2008, respectively, to shift the focus from basic skills and knowledge for operating technology to learning how to use technology effectively.

TPACK

With the shift toward using technology effectively, researchers recognized that effective integration of technology in education required a new knowledge for teachers. Building on the idea of pedagogical content knowledge introduced by Shulman in 1986, researchers began to discuss technological pedagogical content knowledge (TPCK) as the knowledge needed for teaching with technology in an assigned subject or grade level. TPCK was the intersection of content knowledge, pedagogical knowledge, and technological knowledge (Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). The concept of TPCK became so widely acknowledged that

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the American Association of Colleges of Teacher Education (AACTE) supported the collaboration of many TPCK researchers in 2008 to develop *The Handbook of Technological Pedagogical Content Knowledge for Educators*. In the fall of 2007, educational leaders at the National Technology Leadership Initiative discussed the difficulty of saying the acronym TPCK and the implication that TPCK was primarily about integration of technology. They decided to refer to the integration of the three types of knowledge as "TPACK describing it as the total package required for truly integrating technology, pedagogy, and content knowledge in the design of curriculum and instruction preparing students for thinking and learning mathematics with digital technologies" (Niess, 2008, p. 10). In 2009, Niess et al. comprised a set of TPACK standards for mathematics teachers along with a TPACK developmental model for mathematics teachers.

Improving Instruction

Despite all of the initiatives proposed to improve the state of mathematics education, particularly through the effective integration of technology, progress is slow. In their analysis of the TIMSS video study, Stigler and Hiebert (1999) noted that teaching is a complex system and a cultural activity. In general, teachers teach the way they were taught. They suggested that written recommendations alone do not serve the purpose of improving instruction. In contrast, as seen in the TIMSS video study, teachers attempt to make superficial changes, which in turn may actually reduce the quality of their instruction (Stigler & Hiebert, 1999).

Hiebert (2003) stated in regard to teachers' effectiveness in carrying out the educational reform, "Such changes do not happen automatically; they require learning. And learning for teachers, just as for students, requires an opportunity to learn" (Hiebert, 2003, p. 18). Similarly,

most teachers did not have the opportunity to learn mathematics through the use of technology, at least not the same technology that is now available. In a later document, NCTM acknowledged the need for teachers to experience learning with technology. "If teachers are to learn how to create a positive environment that promotes collaborative problem solving, incorporates technology in a meaningful way, invites intellectual exploration, and supports student thinking, they themselves must experience learning in such an environment" (NCTM, 2007, p. 119).

Hiebert (2003) further indicated that, especially in comparison to other jobs concerned with improvement, most teachers have few opportunities to learn new ways of teaching. With several research documents cited, Hiebert (2003) noted that effective teacher professional development programs share common core features.

> These features are (1) ongoing collaboration – measured in years – of teachers for purposes of planning, with (2) the explicit goal of improving students' achievement of clear learning goals, (3) anchored by attention to students' thinking, the curriculum, and pedagogy, with (4) access to alternative ideas and methods, and opportunities to observe these in action (p. 19).

Lesson Study

As an alternative to educational reform practices typically used in the United States, Stigler and Hiebert (1999) recommended implementing Japanese lesson study as a professional development model. Lesson study is a common practice among Japanese educators in which a group of teachers, after agreeing on a topic for a research lesson, collaboratively plan a detailed lesson with knowledge of their curriculum, their students, and their students' thinking in mind. One teacher teaches the lesson while the others observe and record notes. The group then meets

to analyze the strengths and weaknesses of the lesson and revise the plan. Another teacher teaches the revised lesson, while the others observe and record notes. The group meets again after this round of instruction to analyze the strengths and weaknesses and revise the plan. After final revisions the lesson plans and all of its revisions are permanently recorded for future reference. The group then decides the next topic to be researched through their lesson study (Fernandez, 2002; Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999).

The focus of this lesson study process is not to derive one good lesson, but to improve teaching and learning. Through the ongoing collaboration, the teachers learn from each other. The practice of reflective analysis of the lessons carries over into their everyday planning (C. Fernandez, 2005). Research has demonstrated the impact such reflective analysis has on teaching (C. Fernandez, 2005; Lewis & Tsuchida, 1998; Perry & Lewis, 2009). The impact of this practice on technology integration has been studied with preservice teachers (Cavin, 2007; M. Fernandez, 2005, 2010; Suharwoto & Lee, 2005) but has not been examined with inservice teachers.

This study was intended to contribute to mathematics education research by studying the impact of participating in a technology-based lesson study on secondary mathematics teachers' TPACK. This dissertation stemmed from observations made during a previous technology study. A brief background of the previous study will be given to help the reader understand the context of the study. Connections between the practice of lesson study and the TPACK developmental model will be revealed to support the importance of this study.

Background

Having worked in mathematics education since the early 1990s, I have witnessed the evolution of the role of technology in the classroom. I have always been interested in more effective ways to utilize technology to help students gain deeper understandings of mathematics concepts. As a doctoral student, I worked as a graduate research assistant on an externally funded project, which I will refer to as the 2008 – 2010 study, to examine the effects of creating classroom networks with the Texas Instruments (TI) Navigator system and TI-84 graphing calculators on the attitudes and achievement of students who had learning disabilities or were at-risk, defined by eligibility for free or reduced lunch.

The TI-Navigator system is a wireless networking system that allows every student's calculator to communicate with the classroom computer (Texas Instruments, 2009). This system provides instant feedback to the teacher about mathematical understandings and misunderstandings. All students can submit answers to questions or submit equations, points, or lists to meet a given criteria with anonymity or, if the teacher chooses, with the students' names displayed. The screen of the classroom computer is typically projected onto a large screen so that students can see each other's responses, allowing students to analyze their work as well as the work of others.

During this 2008 – 2010 study, I worked with the participating teachers both one-on-one and in professional development settings. I became interested in finding ways to help teachers become more comfortable in using technology in ways that would promote students' understanding and learning.

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Niess et al. (2009) introduced a model to represent stages of development through which mathematics teachers progress as they develop TPACK (see Appendix A). In reflecting on the participants in the 2008 – 2010 study, I began to think about the stages of TPACK development. I realized that the majority of our participants were still on the lower end of the continuum, despite the professional development experiences they had during the study. I pondered what experiences they would need to progress through the stages.

I also noticed that one group of participating teachers worked together in planning their lessons. This group of teachers reported using the technology more regularly than the other groups of teachers. I wondered if the collaborative planning aided the formation of TPACK for these teachers. I wondered if participating in the repeated iterations of designing, analyzing, and redesigning of a lesson through a technology-based lesson study would promote the teachers' TPACK. Researchers have suggested that members of lesson study groups tend to think through the ways for promoting understanding and combating misconceptions as they plan their individual lessons (C. Fernandez, 2005; Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999). Perhaps participating in a technology-based lesson study would promote the same type of reflective analysis in preparing lessons with technology.

Statement of the Problem

Because TPACK is a new theoretical framework in education, there are many areas that still need to be researched. Along with the proposal of the developmental model for TPACK, Niess et al. (2009) called for more research into what experiences promote TPACK development. Although some research exists on TPACK development with inservice teachers (Lee, Suharwoto, Niess, & Sadri, 2006; Richardson, 2009), most of the current research involves

pre-service teachers (Lee & Hollebrands, 2008; Niess & Garofalo, 2006; Schmidt, Baran, & Thompson, 2009; Suharwoto & Lee, 2005).

Relatively new to American education, lesson study has shown promise in helping teachers develop PCK (C. Fernandez, 2005). In 2005, Clea Fernandez determined that lesson study allowed teachers opportunities to discuss issues such as what problems to use in the lesson, how to use manipulatives, what strategic questions to ask students, and when to ask them. She also found that, while participating in lesson study, teachers would discuss how children at different age levels think, considering the misconceptions they might encounter along with strategies to overcome those misconceptions to develop conceptual understanding. These discussions naturally led into opportunities for developing PCK.

Additionally, research has demonstrated that microteaching, a form of lesson study used with pre-service teachers, helps develop PCK and TPACK for those preparing to teach (Cavin, 2007; M. Fernandez, 2005, 2010). Groth, Spickler, Bergner, and Bardzell (2009) designed a model for assessing TPACK through the use of lesson study with inservice teachers. The focus of their research, however, was the assessment model itself, not the development of TPACK (Groth et al., 2009). Research is needed to investigate the effects of participation in lesson study on inservice teachers' TPACK development.

Purpose

The purpose of this study was to describe the progression of secondary mathematics teachers' TPACK development as they participate in a technology-based lesson study. Particularly, the study sought to answer the following research questions.

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1. How does participating in lesson study emphasizing the use of TI-84 graphing calculators and the TI-Navigator system impact secondary mathematics teachers' TPACK?

2. How do teachers' progressions through the stages of TPACK development compare in relation to their educational and technological backgrounds and experiences?

3. What supports do secondary mathematics teachers perceive as important in facilitating TPACK development?

Significance of the Study

With no existing research found on the effects of participation in lesson study on inservice mathematics teachers' TPACK development, this study served to lay a foundation for future research. The thick description of the progression of a small group of inservice mathematics teachers as they participate in a technology-based lesson study gives future researchers some insight with which to perform more studies relating TPACK development and lesson study. In addition, the comparison of teachers' progression through TPACK development in relation to their educational and technological background and experiences and the supports that the teachers perceive as important in promoting their TPACK development serve to address questions posed by researchers in mathematics education (Niess et al., 2009). Providers of professional development may also use the results of this study in planning future sessions aimed at promoting TPACK.

Summary

Mathematics students in Asian countries have outperformed mathematics students in the United States since international testing and comparing began in the 1960s (Medrich & Griffith, 1992; Provasnik et al., 2009). In comparing the actions within mathematics classrooms in Japan

and the U.S., major differences were revealed. Japanese teachers were more successful in implementing educational reforms called for by U.S. professional mathematics education organizations than U.S. teachers were (Stigler & Hiebert, 1999). Increasing technology use in our society has promoted the emphasis of the role of technology in mathematics education. Professional organizations have called for students and teachers to learn to become effective users of technology (AMTE, 2006; ISTE, 2000, 2002, 2007, 2008; NCTM, 2000, 2007, 2008). To integrate technology effectively, teachers need to acquire a special knowledge of the technology combined with deep knowledge of pedagogy and their specific content area (Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). Leading educators formed the acronym TPACK to represent the intersection of technological, pedagogical, and content knowledge (AACTE, 2008). Mathematics teacher TPACK standards and a TPACK development model were proposed to describe teachers' progression in developing this specialized knowledge (Niess et al., 2009).

Lack of improvement in mathematics education has shown that written standards and recommendations for reform do not cause changes within classrooms (Stigler & Hiebert, 1999). Teachers need professional developments that allow ongoing collaboration for the purpose of planning with attention to students' thinking, the curriculum, and pedagogy to improve students' achievement (Hiebert, 2003). They also need to be able to observe alternative ideas and methods in action (C. Fernandez, 2005; Lewis & Tsuchida, 1998; Perry & Lewis, 2009). The professional development model of Japanese lesson study offers such opportunities for teachers (Fernandez, 2002; Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999).

Chapter II describes the specific technology proposed for this study, the TI-Navigator system used with TI-84 graphing calculators, as well as research related to its use. The next

chapter also addresses research associated with TPACK, lesson study, and the similarities between the higher levels of TPACK developmental model and components of lesson study. This relationship will show the importance of this proposed study to the field of TPACK and mathematics education research.

CHAPTER II: LITERATURE REVIEW

Introduction

In an effort to improve mathematics education in the U.S., professional organizations have promoted effective use of technology to engage students in learning and understanding mathematics (AMTE, 2006; ISTE, 2000, 2002, 2007, 2008; NCTM, 2000, 2007, 2008). Researchers have recognized that effective integration of technology requires a special knowledge of the technology, pedagogy, and content (AACTE, 2008; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). This technological, pedagogical, and content knowledge (TPACK) is "the total package required for truly integrating technology, pedagogy, and content knowledge in the design of curriculum and instruction" (Niess, 2008, p.10). Standards and a developmental model specific to mathematics teachers' TPACK serve as a means for common communication among researchers (Niess et al., 2009).

Recognizing that written recommendations do not lead to automatic changes in instructional practices, Stigler and Hiebert (1999) presented lesson study as a form of professional development with a focus on improving teaching and learning within the context of classroom practices. This proposed study seeks to explore the impact of participating in a technology-based lesson study on inservice mathematics teachers' TPACK development specific to the use of the Texas Instruments (TI) Navigator system with TI-84 graphing calculators.

Literature reviewed in this chapter examines the TI-Navigator system, the theoretical framework of TPACK, the practice of lesson study and its implementation in the U.S., and

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studies of professional development designed to promote preservice and inservice teachers'

TPACK. Throughout this review of literature, implications for the use of lesson study

components within professional developments designed to promote TPACK will be revealed.

<div align="center">**Texas Instrument's Navigator System**</div>

Texas Instruments (TI), a developer of educational calculator technology, developed the

TI-Navigator, a wireless calculator networking system that allows each student's graphing

calculator to communicate with the classroom computer. The system was designed to promote an

interactive classroom community to engage more students in their learning. Typically, the

classroom computer screen is displayed on a large screen to be easily seen by all students (Texas

Instruments, 2009).

Research Related to TI-Navigator

Research supports increased student engagement through use of the TI-Navigator system.

The Canton City School District in Ohio reported success among students after incorporating the

TI-Navigator system. The system was implemented in three of the four middle schools in the

district with the fourth school serving as the control group. The teachers were asked to use the

same curriculum as before, but to use the technology to explore the concepts to increase

understanding. Student engagement was no longer a problem in the district, and teachers were

able to differentiate their instruction. Students from classes where the TI-Navigator was

implemented "achieved at a level three times greater" (p. 76) than that of students from classes

that did not use the TI-Navigator (McClure, 2006). No mention was made, however, of pre-

assessments to compare the students' achievement levels before implementation of the TI-

Navigator system.

<div align="center">16</div>

Although some success stories like the one from Canton City School District exist in small numbers, there is little research regarding use of the TI-Navigator. Owens, Demana, Abrahamson, Meagher, and Herman (2002) reported on a study sponsored by the National Science Foundation using a prototype of the TI-Navigator. Following a summer workshop in which 34 teachers received training on pedagogically effective integrations of the technology in the classroom, the teachers used the technology in their classrooms during the spring semester of 2002. Researchers used teacher questionnaires, student and teacher Likert-scale surveys, student focus group interviews, teacher interviews, and formal observations to gather data about the effectiveness of the TI-Navigator prototype in producing learner-, knowledge-, assessment-, and community-centered educational environments. Teachers and students indicated that the TI-Navigator prototype allowed all students, not just those few zealous ones who were normally first to respond, to answer questions anonymously and without fear of embarrassment. Students also reported being more actively engaged in the classroom using the TI-Navigator than in other classrooms and that the use of the TI-Navigator helped them build on their knowledge, relating new concepts to what they already knew. No data was gathered, however, regarding the impact of the system on student achievement.

To support the use of its product, Texas Instruments sponsored more research involving the TI-Navigator system. In research linked to the TI Web site, Dougherty, Akana, Cho, Fernandez, and Song (2005) used attitudinal surveys, pre- and post-assessments, and observations to analyze the impact of using the TI-Navigator in a student-centered classroom. Attitudinal surveys indicated that the experimental group demonstrated positive changes in their attitudes about calculator use after using the TI-Navigator. Content assessments revealed that there was not a

significant difference between the groups' graphing skills; however, the experimental group had more correct answers on conceptual items. Observations revealed differences between interactions within the two groups. Time on task increased in both groups, but the experimental group was quicker to respond to tasks or prompts.

Overall, the researchers found that TI-Navigator use supported "the development of a collaborative classroom environment by enhancing student interactions, focusing students' attention on multiple responses, and providing opportunities for students to peer- and self-assess student work" (Dougherty et al., 2005, Summary, para. 2). Although experimental and control groups both were student-centered environments where students contributed to the majority of the class discussions with the teacher serving as a facilitator, observers noted that the quality of the discussions of the experimental group was more in-depth. The control group used a document presenter to display students' calculator work, but the display was limited to one student's work at a time. With the TI-Navigator, the experimental group could compare and contrast all students' work at the same time, leading to richer discussions. The researchers documented that being able to display all of the students' responses supported "a problem-solving approach to developing skills and concepts" (Dougherty et al., 2005, Summary, para. 2).

Also linked to the TI Web site is later research by Owens, Abrahamson, Demana, Pape, and Irving (2008). The researchers used teacher beliefs surveys, teacher telephone interviews, student beliefs surveys, student motivation questionnaires, and student pre- and post-tests to investigate how implementation of the TI-Navigator system affected student achievement in Algebra I, students' self-regulated learning, and students' dispositions toward mathematics. While no differences were noted in students' beliefs about mathematics, the students from

groups that implemented the TI-Navigator outperformed those students who used calculators alone on the post-test when controlled for students' pre-test scores, teachers' years of experience, teachers' gender, and percent of free/reduced lunch (Owens et al., 2008). The number and nature of covariates utilized to produce a significant difference in students' performance, however, leaves one to question the implication of increased achievement through implementation of the TI-Navigator system.

The 2008 – 2010 research study in which I assisted studied the effects of using the TI-Navigator on the Algebra I achievement and attitudes of students who had learning disabilities or who were classified as "at risk." "At risk" (AR) was defined as students who received free or reduced lunch. Algebra I teachers and students from eight schools participated in the study. The control groups received class sets of TI-84 graphing calculators and TI view screens for use in their classrooms. Teachers from the control groups participated in content professional development. Experimental groups received class sets of TI-84 graphing calculators, TI view screens, and TI-Navigator systems for use in their classrooms. Teachers from the experimental groups participated in the same content professional development as the control teachers, but also participated in professional development for using the TI-Navigator system. Participating students completed a standardized test as a pre- and post-assessment taken without the use of calculators. Students also completed pre- and post-attitudinal surveys.

Findings from the 2008 – 2010 study verified that mean gains from pre-test to post-test were significantly different between teachers and between sites, not a surprising result due to the differences noticed in planning and instructional practices. Data also revealed that AR students made noticeably higher gains in the group with the TI-Navigator than the non-AR students,

although the gains were not statistically significantly higher. The pre-test scores of the TI-Navigator group indicated a significant difference between the mean scores of AR and non-AR students. Analysis of the post-test scores of this group, however, showed no significant difference between the mean scores of AR and non-AR students. While this result demonstrated promise for closing the gap between economically disadvantaged students and their counterparts, teacher-submitted logs of technology use indicated differences in the amount of use of the TI-Navigator among teachers in the experimental group. Other tests comparing mean achievement scores of the two groups revealed no significant differences (Harper & Cabrera, 2010).

While the available research related to use of the TI-Navigator system in general implies promotion of student engagement, increased time on task, richer mathematical discussions, higher achievement on questions of conceptual nature, and potential for closing the achievement gap between economically disadvantaged students and their counterparts, the limited availability of research implies a need for further research. There is a need for more independent research on the use of the TI-Navigator system in the mathematics classroom. Such research, however, would not prove whether using the TI-Navigator is better than not using the system. There are too many other factors that would influence the outcome of such studies, such as the types of questions asked and the focus of the technology use (Hiebert, 2003). Teachers make the important decisions about how to integrate technology into their lessons to promote their students' learning (NCTM, 2000). The decisions that teachers make about how to use technology in their lessons is a result of what they know about their content, pedagogy, and the technology (Niess et al., 2009).

TPACK

In 1986, Lee Shulman introduced a theoretical framework of content knowledge being comprised of subject matter content knowledge, pedagogical content knowledge, and curricular knowledge. With the growing emphasis on teachers' effective use of technology (AMTE, 2006; ISTE, 2000, 2002, 2007, 2008; NCTM, 2000, 2007, 2008) professional educators have built upon Shulman's PCK, adding technological knowledge as another knowledge that is necessary for teachers to integrate with their PCK (Koehler & Mishra, 2009; Mishra & Koehler, 2006; Niess, 2005; Niess et al., 2009, Pierson, 2001).

Knowledge of content (subject matter), knowledge of pedagogy (how to teach), and knowledge of technology (educational technology) are the three main constructs that comprise the technological, pedagogical, and content knowledge (TPACK) framework (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Koehler and Mishra described a framework and presented a model for TPACK. The model, presented as figure 1, includes the three main constructs of content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK), along with the equally important interactions of PCK, technological content knowledge (TCK), technological pedagogical knowledge (TPK). TPACK is the intersection of all three of the main constructs of technology, pedagogy, and content knowledge.
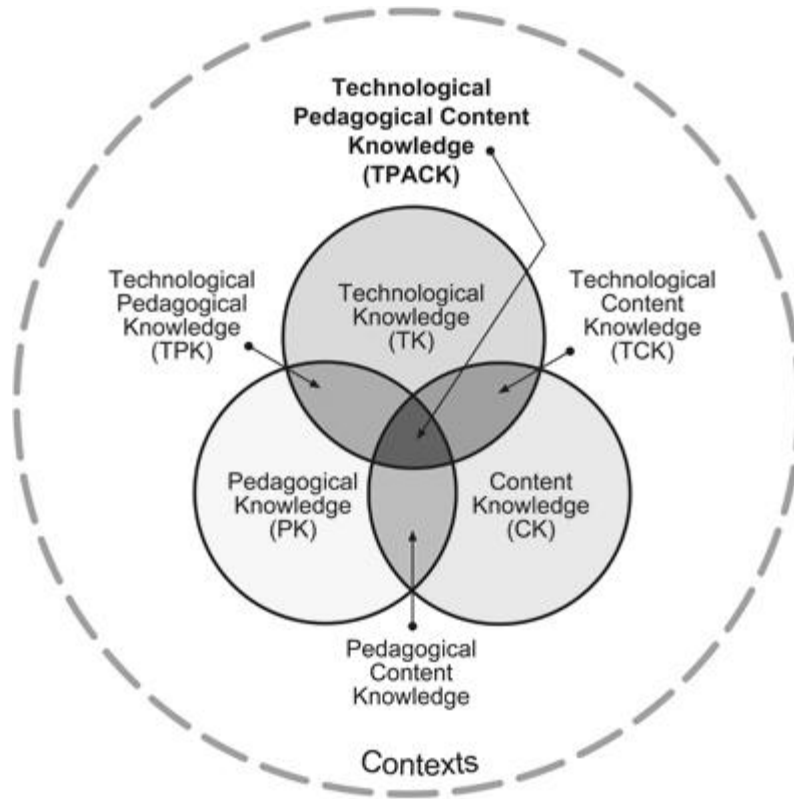
Figure 1. TPACK Model by Koehler & Mishra (source www.tpack.org). Reprinted with permission.

Because the theoretical framework of TPACK is a relatively new concept, Cox (2008) examined literature and interviewed leading TPACK experts to clarify working definitions to be used in discussions among researchers. Cox defined TCK as "an understanding of the technologies that may be utilized in a given discipline and how the use of those technologies transforms the content of that discipline through representation or the generation of new content" (p. 40). Cox also proposed a definition for TPK: "TPK is an understanding of the technologies that may be used in a given pedagogical context, including the affordances and constraints of those technologies, and how those technologies influence or are influenced by the teacher's pedagogical strategies" (p. 42). Cox offered the following as a definition of TPACK: "technological pedagogical content knowledge is a way of thinking about the complex relationships between technology, pedagogy, and content in a specific context which is represented through the carefully considered implementation of technology in a classroom setting in order to help students better understand a particular topic" (pp. 50-51).

Assessment of TPACK

Measuring TPACK has posed problems to several researchers (Koehler & Mishra, 2005; Koehler, Mishra, & Yahya, 2007; Lee & Hollebrands, 2008; Schmidt et al., 2009). Koehler, Mishra, and Yahya (2007) used discourse analysis and their theoretical framework of the seven constructs of TPACK to code excerpts from conversations in a faculty development design seminar in which six faculty and 18 graduate education students worked in teams to design online courses. Conversation pieces were labeled as illustrating evidence of one or more of the seven constructs. Their data were analyzed both quantitatively and qualitatively. The quantitative analysis showed that participants moved from thinking of technology, pedagogy, and content as

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individual constructs toward thinking of the constructs as connected. Qualitative analysis showed similarities and differences at multiple levels suggesting that TPACK development "is a multigenerational process" (p. 740). This discourse analysis, however, was extremely lengthy and tedious.

Lee and Hollebrands (2008) used the constructs of TPACK (Koehler & Mishra, 2005, 2009; Mishra & Koehler, 2006; Niess, 2005) to develop an assessment to measure preservice teachers' understandings related to each of the individual and intersecting constructs of TPACK. They acknowledged the "difficulties in developing measures of teachers' TPACK that go beyond assessing independently a teacher's understanding of technology, pedagogy, and content" (p. 333). They noted that their lengthy paper-and-pencil questions may not have provided a clear, in-depth picture of what the preservice teachers understood about TPACK.

Other researchers have used surveys to measure TPACK. Koehler and Mishra (2005) developed an online survey instrument specifically for use with a group of faculty and graduate education students involved in designing a course for online instruction. Of the 14 questions in this survey, eight questions related to one of the individual constructs of TPACK, two questions related to the intersection of pedagogy and content knowledge, two questions dealt with the intersection of technology and content, one question referred to the intersection of technology and pedagogy, and only one question addressed the intersection of technological, pedagogical, and content knowledge. As with Lee and Hollebrands, this approach measured the knowledge in the different constructs of the TPACK model, but did not give an adequate picture of the knowledge the teachers had in the TPACK intersection.

Similarly, Schmidt et al. (2009) described the design and analysis of a survey for the purpose of preservice teachers' self-assessment of the seven constructs in the TPACK framework. This survey was formed specifically for preservice elementary teachers and analyzed based on the responses of 124 preservice teachers, most of whom had not yet completed a student teaching experience. This survey included more questions addressing all individual and intersecting constructs of TPACK than the previously described survey (Koehler & Mishra, 2005). With the survey having a strong internal consistency reliability, the researchers noted that this instrument was promising for measuring preservice teachers' self-assessment of TPACK. They also indicated that future research would include validating the instrument with classroom observations. Although this survey presented a promising method for measuring self-reported TPACK, the survey was designed specifically for preservice elementary teachers who would be teaching a range of content and was not appropriate for use with secondary inservice mathematics teachers.

TPACK Development Model

With the difficulties in assessing TPACK as the intersection of technological, pedagogical, and content knowledge rather than the knowledge of the individual constructs, researchers needed a common way to discuss TPACK. Additionally, with the majority of assessments created for use among preservice teachers or within a college setting, an assessment model was needed to analyze the TPACK of inservice teachers. Niess et al. (2009) introduced a developmental model through which mathematics teachers progress as their TPACK grows. Four major themes served to frame the TPACK development model: curriculum and assessment, learning, teaching, and access.

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According to this developmental model, TPACK develops as teachers, who begin with developed PCK, move through the stages of recognizing, accepting, adapting, exploring, and advancing for each of the four major themes each time they encounter a new technology. As teachers progress along this developmental model, TPACK – the intersection of the constructs of technology with pedagogy and content knowledge – forms and expands (Niess et al., 2009). Figure 2 illustrates how the constructs of content, pedagogy, and technology intersect through progression of the stages of the TPACK developmental model. Each of the stages of TPACK development will be discussed in greater detail in the paragraphs that follow.
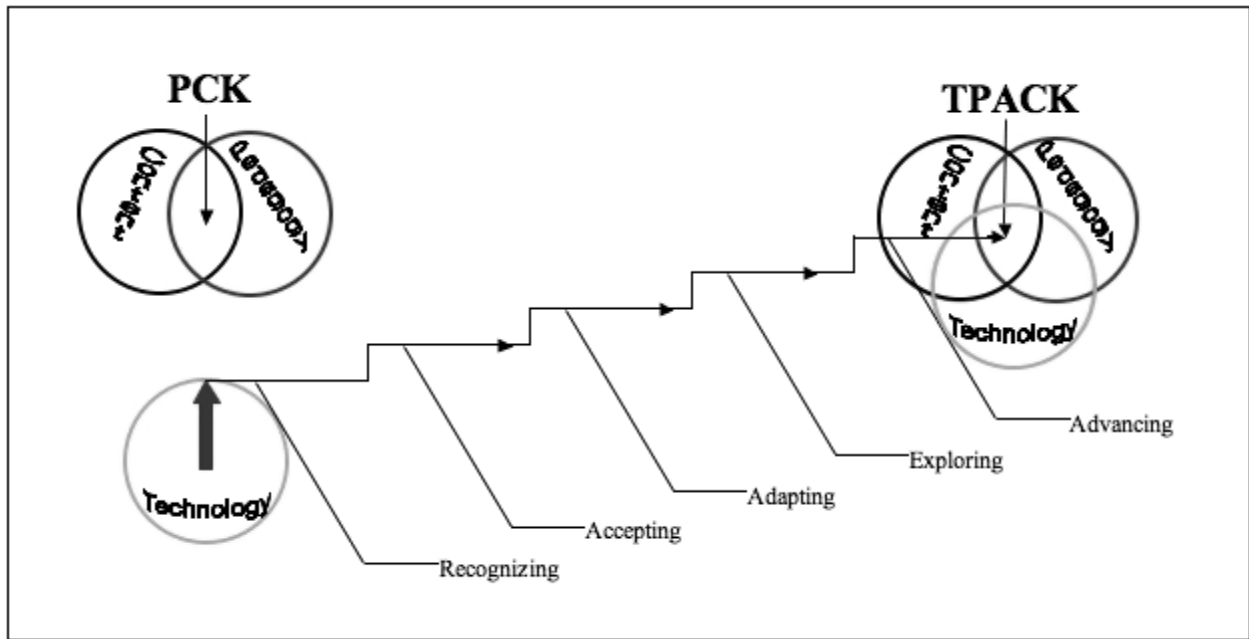
Figure 2. Representation of the TPACK Development Model for mathematics teachers from

"Mathematics Teacher TPACK Standards and Development Model," by M. L. Niess et al., 2009,

Contemporary Issues in Technology and Teacher Education, 9(1), p. 10. Copyright [2009] by the

Society for Information Technology & Teacher Education. Reprinted with permission.

Recognizing stage. In the recognizing stage of TPACK development, teachers are able to use the technology and recognize the potential of its use in mathematics. The teachers, however, do not integrate the technology when introducing new concepts, nor do they allow the use of technology on assessments. These teachers may believe that using the technology will hinder the students' skill development and learning, considering the time spent teaching about the technology as time taken away from teaching mathematics. These teachers may allow the use of technology tools, such as calculators, to solve real-life problems with more complicated computations, but only after their students have shown mastery of paper-and-pencil methods (Niess et al., 2009).

Accepting stage. Teachers in the accepting stage of TPACK development accept the technology as "here to stay" (Niess et al., 2009, p. 12). They express a desire to incorporate the technology into their lessons, but exhibit difficulty in finding ways to integrate the technology effectively in their curriculum. These teachers may seek out technology-based professional development trainings and then mimic the simpler ideas from the trainings in their classrooms. They allow students to use technology to check their answers, but they still limit technology use due to worries about students' attentions being taken away from the mathematics to focus on the technology use. These teachers also tend to demonstrate concern about the classroom management issues related to technology use. The technology use in these teachers' classes is usually skill-based with teacher-led, step-by-step directions (Niess et al., 2009).

Adapting stage. As teachers enter the adapting stage of TPACK development, they begin to demonstrate understanding of some benefits of using appropriate technologies as teaching tools. These teachers start to explore and experiment with integrating technology as learning

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tools to determine whether to adopt or reject the technology. They develop some lessons in which students can use technology to explore mathematical topics and justify concepts previously learned, although the teachers will demonstrate how to use the technology before allowing time for students to explore. They design some assessments allowing technology use that assess students' conceptual understandings in addition to procedural understandings. These teachers also mimic ideas from professional development sessions, but adapt the ideas to meet the needs of their students (Niess et al., 2009).

Exploring stage. By the exploring stage of TPACK development, teachers who have decided to adopt the technology for classroom use begin to examine their own curriculum for topics in which the technology could be effectively integrated. They search for ways to modify existing lesson plans to incorporate the technology as a learning tool that will build students' understanding of mathematical concepts. Through the use of technology, these teachers facilitate their students' learning by engaging them in critical thinking in explorations, problem solving, and/or decision making. With students' learning and attitudes as a guiding factor, they "plan, implement, and reflect on teaching and learning" (Niess et al., 2009, p.12). These teachers "share classroom-tested, technology-based lessons, ideas, and successes with peers" (Niess et al., 2009, p. 23) and organize groups of teachers of similar mathematics courses to explore the curriculum for areas of appropriate integration of technology. These teachers allow access to the technology for explorations of mathematics topics in almost all class meetings and design assessments for extensive technology use to measure students' understandings (Niess et al., 2009).

Advancing stage. In the advancing stage of TPACK development, teachers understand that innovative and appropriate integration of technology into their curriculum as tools for

teaching and learning is vital. The teachers start to modify and advance their curriculum based on the capabilities of the technology integrated. These teachers use the technology to help students develop more advanced levels of understanding of mathematical concepts by engaging the students in high-level thinking and encouraging student-directed learning. Advancing teachers view technology as a means to expand the accessibility of mathematics for students, challenging traditional ideas of what students can master. An advancing teacher "plans, implements, and reflects on teaching and learning with concern and personal conviction for student thinking and understanding of the mathematics to be enhanced through integration of the various technologies" (Niess et al., 2009, p. 22). These teachers may be perceived by others as a resource of novel ideas for learning with technology and may engage other teachers in the district to revise the curriculum to incorporate technology throughout the curriculum effectively (Niess et al., 2009).

This TPACK developmental model serves as a more thorough way to assess teachers' TPACK by analyzing the actions of teachers in relation to the four major themes from the context of the classroom setting. In presenting this model, Niess et al. (2009) noted that TPACK development is not a one-time progression. Rather, it is an iterative process that teachers go through as they encounter new technologies that may be used as learning tools. The authors suggested further study to examine if a teacher's rate of progression through the developmental model could depend on his or her TPACK level for other technologies. The authors also proposed investigation into the experiences that facilitate teachers' progression through the TPACK development model (Niess et al, 2009).

Through the stages of TPACK development, a teacher moves from recognizing the

benefits of a technology in accomplishing the goals of a given curriculum to accepting its use,

adapting lessons to include use of the technology, exploring more areas in the curriculum where

the technology could be used, and finally to advancing the depth of the curriculum under study

through the use of the technology. The exploring and advancing stages of TPACK development

include a focus on student thinking. In these stages teachers design, implement, and reflect on

technology lessons and share proven technology lesson ideas with peers. These same elements of

analyzing student thinking to design, implement, and reflect on lessons are the underlying

components of lesson study, a professional development model with the goal of improving

teaching and student learning.

Lesson Study

In *The Teaching Gap*, Stigler and Hiebert (1999) described major differences observed in

the teaching styles of lessons from the Third International Mathematics and Science (TIMSS)

video study. Stigler and Hiebert noted particular distinctions between Japanese classes and U.S.

classes. Japanese lessons were assigned the motto, "structured problem-solving" (p. 27) while

the lessons from the U.S. received the motto "learning terms and practicing procedures" (p. 27).

Ironically, Japanese lessons better exemplified the kinds of student engagement in critical

thinking, problem solving, and mathematical communication outlined in the 1991 *Principles and

Standards for Teaching Mathematics (PSTM)* promoted by the National Council of Teachers of

Mathematics (NCTM) than the U.S. lessons (Stigler & Hiebert, 1999).

Pointing out that teaching is a cultural activity not learned by "studying books and

memorizing techniques" (p. 108), Stigler and Hiebert (1999) offered Japan's practice of lesson

study as an alternative reform effort. According to C. Fernandez (2002), "The expression *lesson study* is a literal translation for the Japanese word *Jugyokenkyu—jugyo* means *lesson* and *kenkyu* means *study* or *research*" (pp. 393-394). Lesson study is a collaborative, long-term improvement model focused on improvement of teaching and student learning, which allows participating teachers to contribute to their own professional development. Stigler and Hiebert described eight steps typical within the variations of lesson study practiced throughout Japan: defining the problem, planning the lesson, teaching the lesson, evaluating the lesson and reflecting on its effect, revising the lesson, teaching the revised lesson, evaluating and reflecting again, and sharing the results. Stigler and Hiebert commented:

> The premise behind lesson study is simple: If you want to improve teaching, the most effective place to do so is in the context of a classroom lesson. If you start with lessons, the problem of how to apply research findings in the classroom disappears. The improvements are devised within the classroom in the first place. The challenge now becomes that of identifying the kinds of changes that will improve student learning in the classroom (p.111).

Although *The Teaching Gap* (Stigler & Hiebert, 1999) brought national attention to differences between instructional planning and practices between Japanese and U.S. educators, others studied the phenomenon even before this book's release. Lewis and Tsuchida (1998) described the process of lesson study and the student-centered approach of Japanese science lessons. They quoted several Japanese science teachers noting changes in their philosophies of teaching, connections with other teachers, and individual professional reflection. These teachers saw the value of providing students with opportunities to create their own learning rather than

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simply giving them information. When asked about how they made the change to student-centered learning, the teachers described strategies they had learned from research lessons such as using chart paper instead of the chalkboard so that previous lessons could be easily referenced and tracked. They also noted how they thought about and incorporated different ways of asking questions to initiate debate among the students without making the minority feel that they should give in to what others suggest.

Lewis and Tsuchida (1998) also noted the importance of collaboration among Japanese teachers. Quotes from teachers pointed out that the connections among teachers lasted after the formal lesson study ended. Teachers were more comfortable in conferring with other teachers about problems encountered in other lessons. Lewis and Tsuchida also indicated that among students and teachers, collaboration was evident while competition was avoided. Teachers not only planned together several days out of each school year, but they also worked together on many school activities and committees often covering classes for each other because substitutes were not brought in for short-term absences.

Lesson Study in the U.S.

Since the proposal of using lesson study as a model of professional development to improve education in the U.S. over a decade ago, some school districts, small groups of educators, and universities have engaged in trying out this form of teacher collaboration or some adaptation of it (Byrum, Jarrell, & Munoz, 2002; C. Fernandez, 2005; M. Fernandez, 2005, 2010; Kratzer & Teplin, 2007; Lewis, Perry, Hurd, & O'Connell, 2006; Perry & Lewis, 2009; Taylor, Anderson, Meyer, Wagner, & West, 2005). In one of the most extensive examples, Perry and Lewis (2009) described a case study of "a medium-sized California K-8 school district" (p. 368)

involved in ongoing use of lesson study as teacher professional development. Leading the way for others, this district initially implemented its lesson study in 2000, the second U.S. site and the first U.S. district to adopt this practice. At final manuscript preparation, the district was in the seventh year of their lesson study (Perry & Lewis, 2009).

Four district educators initiated the lesson study in this California school district. The three district mathematics coaches/teachers and the instructional improvement coordinator sought "a form of professional development that was teacher-led and relevant to teachers' individual professional needs" (Perry & Lewis, 2009, p. 369). Although the improved mathematics lessons themselves were the resulting product desired during the first year of lesson study, adjustments in implementation began shifting the focus to a "view of lesson study as a *process* for instructional improvement" (Perry & Lewis, 2009, p. 372). District leaders and participants learned from their own practice and made adaptations to their lesson study model that emphasized teacher development along with lesson development.

In gathering data during this case study reported by Perry and Lewis (2009), researchers conducted interviews between 2001 and 2004. Teachers involved in the lesson study reported several changes to their own instruction. These instructional changes included using tasks that promoted student thinking and facilitated student exploration, working through mathematical tasks before presenting them to students to allow for better understanding of the task and anticipating student thinking, allowing students to compare incorrect and correct solutions through mathematical communication, analyzing student data to guide instruction, and telling students the answers less frequently. Teachers also reported more collaboration with other

teachers including asking each other questions, discussing print resources and student thinking, and observing each other and discussing observations.

Taylor et al. (2005) reported an example of lesson study on a smaller scale. Four elementary mathematics teachers worked with a teacher educator toward the goal of improving second-grade students' understanding of two-step word problems in a rural setting. The teachers identified several benefits that they felt were significant from their experience including meeting regularly, sharing and interacting with each other to reassess their practices, and shifting from a "teaching focus to a learning focus" (p. 21). They learned to listen to their students and use their students' thinking as a guide. The teachers also noted that their lesson study experience changed their working relationships, empowered and motivated them, and completely shifted their paradigm. They stated, "We experienced an immediate impact on our thinking and teaching as we talked and worked with colleagues in our school" (p. 21).

Taylor et al. (2005) also made note of some areas of concern about using lesson study in the U.S. The group felt frustrated by external mandates that they believed acted against the best interest of teachers and student learning, although no details were given about these mandates. Shifting from their traditional practices, the ways they were taught and had been teaching for 10 to 25 years, was difficult for this group of experienced teachers. They also stated that they began to understand the goals of lesson study as they went through the process, which took some time. Finally, the group of teachers acknowledged that support from the administration was necessary for the success of lesson study and suggested having substitute teachers for the days that the research lesson was implemented (Taylor et al., 2005).

M. Fernandez (2005) used microteaching lesson study (MLS), an adaptation of lesson study used with preservice teachers. After collaboratively planning lessons, groups of secondary mathematics preservice teachers taught their respective lessons to small groups of peers in the same course. Each group completed a written assignment, which consisted of five sections that guided them through the phases of MLS: pre-lesson thoughts and lesson plan; video of first implementation of lesson, analysis of the lesson, and revised lesson plan; video of second implementation of lesson, analysis of the lesson, and revised lesson plan; video of third implementation of lesson, analysis of the lesson, and final revisions; and final revised lesson with suggested teaching strategies (M. Fernandez, 2005).

Based on NCTM's 1991 standards for teaching mathematics, analyses of the lessons were conducted with a video analysis framework. The instructor provided feedback of video-taped lessons during the phases of MLS. The researcher gathered and kept field notes of observations and interactions of groups. At the end of the MLS experience, preservice teachers completed final surveys to assess their thoughts about the lesson feedback, lesson analysis, group collaboration, and understandings of reform-oriented teaching. The researcher coded these data sources to note the pedagogy used and the knowledge of the subject matter presented. Coding within the lessons served to compare student-centered instruction and teacher-centered instruction. The researcher also coded written assignments and observation notes to indicate the prospective teachers' learning about pedagogy and content as well as their perceptions of the MLS experience. All of the findings were triangulated to confirm (or not) emerging themes (M. Fernandez, 2005).

Analysis of the video-taped lessons and the written lesson plans indicated that by engaging in the MLS, the second lessons implemented by prospective teachers were less teacher-centered and incorporated more student exploration and reasoning than the first lessons. Prospective teachers expanded their mathematics content knowledge, and their participation in MLS facilitated PCK growth, the beginning foundation for TPACK development (M. Fernandez, 2005).

C. Fernandez (2005) reported on the lesson study work of a group of elementary mathematics teachers from an urban public school in the northeastern U.S. The purpose of this study was to explore whether lesson study provided opportunities for teachers to learn about mathematics in ways that are useful for carrying out reform-minded teaching. The researcher analyzed detailed field notes and video-taped recordings of all of the meetings and both research lessons. After transcripts were prepared, the researcher viewed the tapes several times while reviewing the transcripts, field notes, and lesson artifacts. She broke the conversations down into threads that were related to the design or implementation of the lesson and identified exchanges in which teachers discussed the mathematics of the lesson and how best to teach the mathematics (C. Fernandez, 2005).

C. Fernandez (2005) determined that lesson study allowed the teachers opportunities to discuss issues such as what problems to use in the lesson, how and when to implement manipulatives, what strategic questions to ask students, and when to ask them. Teachers also discussed how children at different age levels think and the misconceptions they might encounter along with strategies to overcome those misconceptions and develop conceptual understanding. These discussions naturally led into opportunities for developing PCK, the needed foundation for

TPACK development. She also inferred that lesson study provided for discussion about unexpected events, a phenomenon likely to occur when implementing technology, and how to handle these situations. These discussions allowed the teachers to develop mathematical reasoning that would promote better decisions during the execution of lessons (C. Fernandez, 2005).

In each of the studies cited here, participating in lesson study prompted the teachers to turn their focus toward student thinking to guide their decisions about lessons (C. Fernandez, 2005; M. Fernandez, 2005; Perry & Lewis, 2009; Taylor et al., 2005). The cooperation, collaboration, and observations among the teachers fostered reflective analysis of teaching practices and provided opportunities for teachers to expand their knowledge of pedagogy and content. According to the TPACK development model presented by Niess et al. (2009), a developed PCK is the beginning foundation for TPACK development. Additionally, the later stages of the TPACK development model include a focus on student thinking to design, implement, and analyze technology lessons. In the later stages of TPACK development, teachers share their proven lessons with their peers. Thus, these elements of TPACK development may potentially result from participation in lesson study.

<p style="text-align:center">Lesson Study and TPACK</p>

Elements of TPACK development resulting from participation in lesson study imply that lesson study would be an appropriate form of professional development in seeking to promote TPACK development. No research has been conducted that utilized lesson study as a means of promoting TPACK development for inservice teachers; however, some researchers have incorporated components of lesson study in studies examining TPACK with preservice and

inservice teachers. One set of researchers proposed a model for assessing TPACK through lesson study, although no results were reported as to whether or not participation in lesson study facilitated growth in TPACK. The following paragraphs further discuss these TPACK studies that utilized components of lesson study and the model for assessing TPACK through lesson study.

Components of Lesson Study in Promoting TPACK

Some TPACK studies specific to mathematics preservice and inservice teachers have integrated components of lesson study (Cavin, 2007; Lee & Hollebrands, 2008; Richardson, 2009). Lee and Hollebrands (2008) described and gave examples of materials prepared for a teacher education program by the Preparing to Teach Mathematics with Technology (PTMT) project. The examples given were focused on statistics and probability. Based on components of TPACK (Koehler & Mishra, 2005; Niess, 2005) and recommendations from the Association of Teachers of Mathematics Educators (AMTE) (AMTE, 2009), the program integrated mathematics content with technology and pedagogy with an emphasis on student thinking (Lee & Hollebrands, 2008).

In the PTMT program, preservice teachers participated as learners in a mathematics technology task, reflected from the view of teachers on how students might think through the same task, and then watched a videocase designed to highlight the student thinking through the same task. The preservice teachers then analyzed student thinking and worked through group discussions. Lee and Hollebrands reported, "While analyzing students' work, the prospective teachers engage in reasoning that is at the intersection of technology, pedagogy, and content" (Lee & Hollebrands, 2008, p. 332). Focusing on and predicting student thinking in a technology

task, observing and reflecting on a technology lesson, and discussing with peers were components of lesson study integrated in the implementation of this program that facilitated the preservice teachers' TPACK reasoning.

Also allowing teachers to participate as learners with technology and then focus on students' thinking while planning technology lessons, Richardson (2009) described a qualitative study designed to allow eighth-grade Algebra I teachers the opportunity to "develop, explore, and advance [TPACK] in the teaching and learning of algebra" (p. 117). Twenty middle school teachers from six different schools (three from a rural setting and three from an urban setting) from the same district participated in professional development sessions, consisting of fifteen four-hour sessions during the summer and fifteen four-hour sessions during the academic school year. Summer sessions focused on a conceptual understanding of the content knowledge while sessions during the academic year emphasized "pedagogical techniques for developing and implementing effective Algebra I classroom activities and instruction for all students" (Richardson, 2009, p. 119).

After thinking through tasks as learners with technology, the teachers worked in small groups to modify five district lesson modules to incorporate the use of technology, specifically virtual manipulatives. The teachers worked together to think about how the manipulatives could be used to introduce new mathematical concepts and/or investigate and understand mathematical ideas. Together the teachers worked through the purpose and design of the lessons, similar to the type of collaborative planning found in lesson study. During the lesson modifications, several examples of teachers' development of PCK, TCK, TPK, and TPACK were documented (Richardson, 2009).

Building on the work of M. Fernandez (2005), Cavin (2007) examined as part of her doctoral dissertation the changes in TPACK in preservice teachers after participating in MLS and the aspects of the MLS experience that facilitated these changes. In her study, nine preservice teachers enrolled in a technology education course for preservice teachers worked in groups of three to plan lessons collaboratively to teach to students enrolled in an undergraduate mathematics course. Preservice teachers carried out three iterations of planning, implementing, and revising the lesson. Each implementation of the lesson was video recorded for analysis and for gathering data (Cavin, 2007).

Three preservice teachers, one student from each MLS group, were selected for an in-depth case study analysis. Two interviews were conducted with these students during the semester, one interview following the participant's teaching of the group's lesson and the other after the completion of the MLS process. The first interview utilized questions to gather data about the effects of participation in the modeled lesson on decisions made in developing the group lesson. Questions in the second interview focused on the development of TPACK as a result of participation in the MLS process. All nine preservice teachers provided feedback through course documents such as video feedback forms and surveys. Using TPACK as a theoretical framework, the researcher analyzed the qualitative data from the surveys, interview transcripts, audio recordings of MLS group meetings, and other course documents (Cavin, 2007).

Overall, the preservice teachers demonstrated growth in TPK, TCK, and TPACK following participation in the MLS process. The aspects of the MLS process that served to promote TPACK were collaborative planning, teaching in a controlled environment, analyzing and revising the lesson, and developing ownership for the final lesson plan. The combination of

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these aspects of the MLS process, a process adapted from lesson study, promoted the development of TPACK in the secondary mathematics preservice teachers (Cavin, 2007).

Assessment for TPACK Development through Lesson Study

Groth, Spickler, Bergner, and Bardzell (2009) presented a lesson study technological pedagogical content knowledge (LS-TPACK) assessment model as a means for assessing the TPACK development of a group of teachers as they progressed through cycles of lesson study. An example of the LS-TPACK in use was given, however, the article focused on the assessment model itself, not on the TPACK development of the teachers involved in the pilot (Groth, Spickler, Bergner, & Bardzell, 2009). The following paragraphs describe the processes involved in using the LS-TPACK assessment model.

For this qualitative data gathering, inservice teachers prepare four-column written lesson plans for a lesson that will incorporate technology. A facilitator sends this lesson plan and any worksheets or handouts to be used to a university faculty member for review to assist in identifying pedagogical and content-related weaknesses in the lesson. The university faculty member returns the lesson plan along with feedback to the group of teachers. The group of teachers decides which feedback to use to revise the lesson plan. The university faculty member may become involved in the planning if the group requests help (Groth et al., 2009).

Once lesson revisions are complete, one member of the group implements the lesson while another member video records and, ideally, other members of the group and the university faculty member observe. The whole group debriefs and reflects on the lesson through reviewing the video recording. Participants record perceived strengths and weaknesses of the lesson while viewing the video. Each member shares one strength and one weakness of the lesson starting

with the teacher who taught the lesson and ending with the university faculty member. Further

conversation follows which may turn toward goals for the next lesson (Groth et al., 2009).

Researchers gather qualitative data through this process, including the original and

revised written lesson plans, feedback from the university faculty member, transcripts of the

implemented lesson and transcripts of the debriefing session. The researcher uses the case study,

along with comments from the university faculty member about teachers' use of technology from

feedback, and transcripts to make inferences about the TPACK level of the group of teachers.

The researcher compares these inferences against the implemented lesson and the teachers'

comments during the debriefing session. From this comparison, the researcher draws conclusions

about the teachers' TPACK. The university faculty member validates the conclusions (Groth et

al., 2009).

In addition to the description of the model and the example of the pilot study, Groth et al.

(2009) reflected on strengths and weaknesses of the LS-TPACK assessment model. Strengths

included that TPACK assessment was intertwined with professional development, the university

faculty member offered a review of the lesson providing a learning experience for the teachers,

and the lesson study model allowed for the simultaneous study of content, pedagogy, and

technology. Another strength was the teamwork formed by bringing together the expertise of

mathematicians, mathematics educators, and teachers. Weaknesses included that repeated use of

the LS-TPACK assessment might lead to participants learning what the university faculty

reviewer expects. In this case, the participants might begin writing lesson plans to satisfy those

expectations without sincere reflections and analysis of their teaching practices and their

students' thinking. Another weakness was that the LS-TPACK measured TPACK development

of a group of teachers and did not provide a means to measure an individual teacher's knowledge (Groth et al., 2009).

Summary

Within the developmental model for TPACK presented by Niess et al. (2009), the exploring and advancing levels included components of lesson study, namely focusing on student thinking; designing, implementing, and reflecting on technology lessons; and sharing proven lesson ideas with peers. Lesson study research (C. Fernandez, 2005; M. Fernandez, 2005, 2010; Perry & Lewis, 2009; Taylor et al., 2005) has shown that lesson study promotes the development of PCK, the foundational framework for TPACK development. In addition, TPACK research involving components of lesson study (Lee & Hollebrands, 2008; Richardson, 2009) has facilitated development of preservice and inservice teachers' TPACK. Furthermore, the work of Cavin (2007) demonstrated that engaging secondary mathematics preservice teachers in MLS served to expand TPACK. Research has not yet been reported, however, on the use of lesson study to promote the TPACK development of inservice mathematics teachers. Chapter III outlines the methodology used to examine the impact of participation in a technology-based lesson study on inservice mathematics teachers' TPACK development.

CHAPTER III: METHODOLOGY

Introduction

Technological, pedagogical, and content knowledge (TPACK) is the special knowledge needed for educators to integrate technology effectively into their lessons in ways that promote students' understanding (Koehler & Mishra, 2009; Mishra & Koehler, 2006; Niess, 2005, 2008; Niess et al., 2009). The TPACK developmental model proposed by Niess et al. (2009) describes stages through which mathematics teachers progress as they develop TPACK for a given technology. According to this developmental model, teachers with developed pedagogical content knowledge (PCK) progress through the stages of TPACK development as their knowledge of technology becomes more integrated with their PCK. The more advanced stages of TPACK include practices such as designing, reflecting on, analyzing, and revising technology lessons with a focus on students' thinking guiding the process (Niess et al., 2009). These practices are the main components of lesson study, a professional development model with a focus on improving teachers' instruction and students' learning which has been shown to provide opportunities for teachers to increase their PCK (C. Fernandez, 2005; M. Fernandez, 2005; Stigler & Hiebert, 1999). TPACK research has shown that components of lesson study such as collaboratively planning technology lessons, observing technology lessons with a focus on students' thinking, and analyzing the strengths and weaknesses of technology lessons serve to promote teachers' TPACK (Cavin, 2007; Lee & Hollebrands, 2008; Richardson, 2009).

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This study aimed to examine secondary mathematics teachers' TPACK development through participation in a technology-based lesson study. This chapter describes the methodology used in this study. First, the research questions will be stated, followed by a description of the research design and the participants. The instruments used will be described in relation to how they served to answer the research questions. Phases of the study described in the procedures section precede an explanation of the data analysis performed to address each of the research questions. Finally, limitations and delimitations of the study will be discussed.

Research Questions

Recognizing the potential for participation in lesson study to promote teachers' TPACK and to address questions posed by other TPACK researchers, this study sought to answer the following research questions.

1. How does participating in lesson study emphasizing the use of TI-84 graphing calculators and the TI-Navigator system impact secondary mathematics teachers' TPACK?

2. How does teachers' progression through the stages of TPACK development compare with respect to their educational and technological backgrounds and experiences?

3. What supports do secondary mathematics teachers perceive as important in facilitating TPACK development?

Research Design

To study the phenomenon of TPACK development while participating in a technology-based lesson study, a layered case study design was implemented (Patton, 2002). For this layered case study, I have provided thick descriptions of the experiences of the whole group participating in the lesson study as well as more detailed cases of four of the individuals. In gathering data

during my study, I made an audit trail through researcher journal entries to document the research process with links between the research questions, the data gathered, and the findings. I also utilized truthfulness, being honest and straightforward with my participants, and in my reporting. Crystallization, a term proposed by Richardson (2000) to replace the term triangulation, recognizes that qualitative research can have "an infinite variety of shapes" (p. 928). To ensure thorough data collection, I incorporated crystallization of data, gathering data from a variety of sources with a variety of methods, including surveys, pre/post interviews, pre/post observations, writing prompts, and lesson plans. I have also described the context of the study with rich description, incorporating tacit knowledge to interpret unspoken language such as long silences, nods, or other gestures. I utilized repeated observations to increase the reliability of the case studies (Gall, Gall, & Borg, 2007).

Participants

The participants were secondary mathematics teachers from a rural high school that houses public high school students from the entire county as well as several students from surrounding counties. Because the study proposed to examine TPACK associated specifically with use of the TI-Navigator system, I selected this school because of the participation as a control site for the 2008 – 2010 study. The four Algebra I teachers at this school received TI-Navigator systems as a result of their participation in the 2008 – 2010 study. Of the schools that participated as control sites, this school was selected partly for convenience to the researcher, but also for the varied backgrounds, ages, and years of experience of the mathematics teachers.

Of the nine mathematics teachers at this school, seven teachers originally consented to participate in the study. For ease of discussion, pseudonyms were assigned to the participants:

Amy, Beth, Carol, Dana, Eric, Fran, and Gina. Fran taught transition to algebra, a class designed for students who may not be ready for Algebra I. Because she did not have a classroom set of TI-84 graphing calculators and because she had committed to after-school tutoring every day of the week, she chose to opt out of the study after the initial meeting, initial interview, and initial observation. The other six participants had a classroom set of TI-84 plus graphing calculators. Beth, Carol, Eric, and Gina had the TI-Navigator systems. Gina served as the team leader for the mathematics department at the high school. The courses taught, teaching experience, and educational backgrounds of the six participants are detailed in Table 1.

Table 1

Courses Taught, Teaching Experience, and Educational Backgrounds of Participants

Pseudonym	Courses taught	Teaching experience	Educational Background
Amy	Geometry	3 years	B.S. in secondary mathematics education; working on master's degree in teaching English as a second language
Beth	Algebra I & Calculus	3 years	B.S. in secondary mathematics education; final semester in master's program for secondary mathematics education
Carol	Algebra I & transition to algebra	18 years	B.S. in elementary education
Dana	Algebra II & physics	10 years	B.S. in electrical engineering
Eric	Algebra I & trigonometry/ Pre-calculus	31 years	B.S. in secondary mathematics education
Gina	Algebra I & Algebra II	20 years	B.S. in secondary mathematics education

Instruments

As the researcher, I served as the main instrument for measure (Cresswell, 2009; Gall, Gall, & Borg, 2007). To offer credibility as a research instrument, I offer some background information. I served as a secondary mathematics teacher in the same state as my research site for seventeen years, teaching every secondary mathematics course from seventh-grade

mathematics to advanced mathematics. I obtained certification by the National Board of Professional Teaching Standards in 2001. While serving as a teacher, I enrolled at a local university as a part-time graduate student in fall 2005. I obtained my master's degree in curriculum and instruction with emphasis in secondary mathematics education in summer 2007. In fall 2008, I returned to the university as a full-time graduate student, simultaneously pursuing a Master of Arts in mathematics and a doctoral degree in education with an emphasis in secondary mathematics education. At this time I began working as a research assistant for a center at the university and became involved in the 2008 – 2010 research study as well as other research and outreach projects. I have attended and presented at state, regional, and national professional conferences. I completed requirements for a Master of Arts in mathematics in spring 2010 and am now a doctoral candidate in education.

A colleague and I collaboratively created the instruments used in this study. This colleague was another mathematics education doctoral candidate who was also studying TPACK. This colleague obtained bachelor's and master's degrees in secondary mathematics education and had experience teaching secondary mathematics. She also served as a research assistant in the 2008 – 2010 study, providing professional development for participating teachers and maintaining a database of the teachers' self-reported technology use. She had presented at regional, state, and national professional conferences. Her doctoral dissertation researched teachers' perceptions of their own TPACK development compared to their TPACK development determined through classroom observations and interviews.

This colleague peer-reviewed the Background Survey of Education and Technology and writing prompts. My colleague and I worked together in creating and revising the TPACK

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Development Model Self-Report Survey, the interview protocol, and the observation protocol. All of these instruments are included in the appendix of this document. The following sections provide more details about each instrument.

Background Survey

The Background Survey of Education and Technology (see Appendix B) gathered data related to the participants' educational and personal experiences with technology. Participants provided information about their educational backgrounds and their uses of technology in their own educational experiences. They also described technology that they incorporated in their classrooms as well as in their personal lives and the purposes for which these technologies were used. This data allowed the researcher to compare the participants' progression through the TPACK development model based on their educational backgrounds and experiences with technology.

TPACK Development Model Self-Report Survey

The TPACK Development Model Self-Report Survey (see Appendix C) utilized statements about technology use as related to the four themes described in the TPACK Development Model (Niess et al., 2009). Five statements, one for each level of TPACK development, were provided for each theme and descriptor. The participants selected the statements with which they agreed. The evaluation page was used to match the statement number with the assigned TPACK stage in the developmental model for that given theme. In some instances participants agreed with more than one of the statements or they did not totally agree with any of the statements. Following each set of five statements was a space where participants provided any additional comments or explanations about their personal beliefs. These additional

explanations were used to make or verify decisions about the participants' TPACK level for that particular theme and descriptor.

Statements used in the TPACK Self-Report Survey were adapted from examples of the TPACK stages of development for each of the major themes (Niess et al., 2009). Dr. Margaret Niess, a leading mathematics education TPACK researcher, reviewed the survey as a credible critic and suggested some revisions. My colleague and I adjusted the survey based on Dr. Niess's recommendations (personal communication, October 8, 2010).

Interview Protocol

The interview protocol (see Appendix D) consisted of a set of questions in an intended order to help make decisions about the participants' TPACK levels. Knowing that self-reported data is often biased (Ivy, 2011; Kopcha & Sullivan, 2006; McCrory, 2010), the interview questions were designed to ask the participants for more information about their use of technology to allow a more accurate determination of their TPACK levels.

Observation Protocol

The observation protocol (see Appendix E) provided a set of indicators related to levels of TPACK development to document during pre- and post-observations. The specific indicators were designed to bring the observer's attention to actions related to the four themes of the development model. The protocol also allowed space for documentation of general observation notes with times. Using this protocol allowed organized gathering of data related to the TPACK development levels during observations. Data gathered from the observations were analyzed with data from the TPACK Development Model Self-Report Surveys and the interviews to make clear determinations of TPACK levels.

Writing Prompts

Writing prompts allowed the participants to express their beliefs about effective technology integration in a mathematics classroom. The participants completed writing prompts after the Teachers as Learners Phase (see Appendix F) and after the Lesson Study Phase (see Appendix G) to express their beliefs about effective technology integration and to analyze the usefulness of the elements of the study. The writing prompts asked the participants to reflect on aspects of the study and rate the elements according to how effective they were in shaping their thoughts about effective technology integration in a mathematics class. Responses to these writing prompts were used to track TPACK development throughout the study, to address the first and second research questions, and to gain insight about the participants' perceptions of the supports needed to facilitate TPACK development for addressing the third research question.

The TPACK Self-Report Survey, interview protocol, observation protocol, and writing prompts served to gather information about the participants' pre- and post-TPACK levels. Data was also collected from video recordings of group meetings and lessons. Information from all of these sources provided data to describe the participants' progression through the TPACK development model as they participated in the technology-based lesson study, addressing the first research question describing how participation in a technology-based lesson study affects teachers' TPACK development. Information from these sources along with the Background Survey of Education and Technology provided insight for the second research question regarding how teachers' progression through the TPACK development model compares to their educational and technological backgrounds and experiences. The third research question, supports perceived by teachers as important in facilitating TPACK development, was addressed

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by data gathered from the writing prompts throughout the study. The procedures and timeline for this data collection will be described in the following section.

Procedures

At the beginning of the school year, I met with the administrator and presented a brief overview of my proposed study with the potential advantages for his teachers. After this meeting, he promptly provided a letter of intent for participation in this proposed study. I defended my prospectus to my dissertation committee and applied for IRB approval. After IRB approval, I began implementation of the planned procedures. Table 2 gives a timeline of the phases of procedures for this study along with data gathered and the research question the data addressed. The paragraphs that follow give more detailed descriptions of each phase.

Table 2

Timeline for Phases of Study

Phase	Begin Date	Duration	Data Gathered	Research Question(s) Addressed
Initial Phase	November 17, 2010	2 weeks (interrupted by Thanksgiving vacation)	Background Survey of Education and Technology, TPACK Self-report Survey, initial interviews, initial classroom observations	1, 2, & 3
Teachers as Learners Phase	December 1, 2010	2.5 sessions	Writing prompt 1	1 & 3
Understanding Lesson Study	January 5, 2011	1.5 sessions		
Lesson Study	January 12, 2011	6 weeks	Recordings of group meetings, lesson plans, writing prompt 2	1 & 3
Final Phase	February 16, 2011	4 weeks	Post interviews, post classroom observations	1 & 3

Initial Phase

In mid-November, after obtaining approval from my dissertation committee and the IRB, I invited the mathematics teachers from the school to an after-school meeting to inform them of my study. Seven teachers attended the after-school meeting, which was held in Gina's classroom. I distributed the information sheets that briefly described my study and answered teachers' questions related to the study. All seven of the teachers in attendance consented to participate.

The participants completed the TPACK Self-Report Survey and the Background Survey of Education and Technology. Fran, Carol, and Eric wanted more time to reflect in completing the Background Survey of Education and Technology, so I allowed them to take it with them to complete before the next group meeting.

During the initial meeting, I asked participants to schedule a time that would be convenient for them to complete the initial interview and for me to perform a classroom observation. The participants indicated some concern about planning a technology lesson for my observation. I informed them that I wanted to see how they and their students use the technology on a regular basis. I did not want them to plan a special lesson for the observation. I conducted six of the seven initial interviews on the Friday before Thanksgiving vacation with the seventh interview the week following Thanksgiving vacation. I completed all of the initial classroom observations during the two weeks following Thanksgiving vacation.

Teachers as Learners Phase

Before teachers can incorporate technology in a meaningful way with problem solving and exploration that supports students' thinking, they must experience learning in such a way (NCTM, 2007). I planned and facilitated professional developments to allow the participants the experience of learning with the TI-Navigator system and the TI-84 plus graphing calculators. The professional developments were also designed to prepare the participants for their roles in the lesson study, focusing on students' understandings. The professional development consisted of two sessions, each lasting two hours. These sessions were video recorded for later analysis.

Session one. The goals of the first session were to allow the participants the opportunity to learn through technology and to reflect pedagogically on their learning content through use of

the technology. In this first session, I gave the participants a handout with a quote from Hiebert (2003), "Students learn what they have an opportunity to learn," and a brief description of the five process standards from NCTM's *PSSM* (2000). I described the example from Hiebert's work (2003) of fifth-grade students sitting through a calculus lecture and how they might learn to sit respectfully, but they were not likely to learn any content from that experience. I asked the participants to reflect on the opportunities they provide for their students and what their students were learning. Although I did not ask the participants to share what opportunities they presented for their students, I shared my confession of what my students had the opportunity to learn before I learned about standards-based instruction, instruction in which students engage in the five process standards as a means for learning mathematics. I called the participants' attention to the five process standards from NCTM (2000) on their handout. I also briefly described TPACK and asked the participants to think about the content involved as well as the different technological and pedagogical issues that might arise in using tasks similar to those they would be working through during the sessions.

During this Teachers as Learners Phase, I wanted the participants to experience learning with various functions of the TI-Navigator system. The first session was conducted in Gina's classroom, where a TI-Navigator system was set up for use displayed on an interactive whiteboard at the front of the room. After introducing teachers to NCTM's process standards and TPACK, I led the participants through accessing the TI-Navigator system. I began the TI-Navigator explorations with a Quick Poll asking the participants to enter an expression that was equivalent to $5x - 3$. Due to the limited number of characters allowed in a Quick Poll, however, the prompt I sent out read, "Enter an expression equal to $5x - 3$," although I explained verbally

that I wanted them to submit an equivalent expression. When the responses were displayed, I asked the participants to analyze the different responses. One participant submitted a numerical value. From this submission, a discussion arose about the importance of using proper mathematical vocabulary and helping students to understand the differences in equality (in equations) and equivalent expressions. Other submissions included different equivalent expressions to represent the given expression. Some responses demonstrated the distributive property, and some used fractional representations. Following discussion of the different responses, I asked the participants to consider how this approach to examining equivalent expressions was different from giving an expression to simplify, such as $5(x + 1) - 2$. I indicated to the participants that this use of reversibility and open-ended responses provides accessibility for more students, allowing an examination of a wide variety of algebraic expressions while promoting analysis of and communication about the various responses. The participants indicated that this type of questioning deepened the level of thinking for the students.

Following this exploration of equivalent expressions, I guided the participants to the Activity Center of the TI-Navigator. I entered the original expression $5x - 3$ in the "Y = "blank." I then entered other expressions submitted by the participants to allow a visual verification of the equivalence of their submissions to the original expression. Dana asked how this might be used to help students gain a better understanding of solutions of equations. I presented an equation in one variable and asked the participants to think about how they might find the solution using the technology. Some participants worked individually, and some chose to work with a partner. After a few minutes, I used the screen capture feature of the TI-Navigator to display the different ways the participants had thought about solving the equation. The participants shared their

thinking with each other. Then I presented an inequality in one variable and again asked the participants how they would use the technology to find the solution. After a few minutes, I again used the screen capture feature to display the different representations and asked participants to share their thinking with each other.

Following completion of the tasks of this first professional development, I led participants through reflecting and discussing the pedagogical and technological issues associated with the task using the Task Debriefing Questions (see Appendix H). Through these explorations with the graphing calculators and TI-Navigator system and the reflective discussion, the participants had the opportunity to examine the content through the technology and to begin thinking about how they might use the technology with their students, thus providing an opportunity to strengthen their TPACK. All six of the participants were present for this session.

Session two. The goal of the second session was to provide an opportunity for the participants to again learn with the technology and to understand how technology can be used to facilitate students' development of conceptual understanding. During the second session, which was also held in Gina's classroom, I guided the participants to access the TI-Navigator system and enter the Activity Center. I asked the participants to submit points that would meet given criteria. After participants had a few minutes to make submissions, I led the participants to think about the content that could be examined using a task such as this. I also asked the participants to develop an equation that would represent all of the points that met the criteria. In addition, I had planned for the participants to work through a task on the TI-Navigator Activity Center that would utilize a picture of a map loaded as a background image and involve the participants in finding the equation of a line that represented the straight path between two towns. Every time I

tried to import the image into the Activity Center, however, the computer system would not respond. This technical difficulty opened an opportunity for discussion about having an alternate plan for instances such as this. As an alternative plan, I displayed the image alone on the screen and described the task. After allowing the participants some time to think about the task, I asked them to predict how students would react to tasks such as those they had worked through during this session.

Using a method similar to that described by Lee and Hollebrands (2008), I wanted the participants to examine a video case study of students of the same age and similar demographics as their own students working through tasks similar to those through which they had worked. After a brief discussion of how the participants felt their students might react and respond to these tasks, I described the setting for a lesson I had video-recorded of students from a nearby school with similar demographics performing a similar task. I asked the participants to take notes focusing on the students' thoughts and learning. The participants watched portions of the video of the lesson with students performing tasks similar to those explored in the professional development. Following the video, I used the Video Discussion Questions (see Appendix I) to lead the participants through a discussion of the students' reactions and responses as well as ways that the lesson might be changed to promote students' understanding. Through this lesson observation and discussion, the participants prepared for the lesson study by focusing on students' work and responses and thinking through how the lesson plan affected students' understanding. The participants requested to be able to continue working through TI-Navigator tasks during our meetings. At the end of the second professional development session,

participants completed the first writing prompt (see Appendix E). All six participants were present during this session, although Eric came in late, just prior to viewing the video case.

Understanding Lesson Study Phase

Before engaging in the planning stage of lesson study, the participants needed to understand more about the lesson study design, thus we entered the Understanding Lesson Study phase of the study. The group meeting was in Beth's classroom, because Beth's planning time was the last period of the day, allowing time for me to prepare the room for the session. Beth's classroom also had the TI-Navigator system set up for use displayed on an interactive whiteboard. I began the session with a TI-Navigator exploration for three reasons. First, the participants requested more experience with learning with the TI-Navigator. Second, the technology did not work properly in the prior session. Third, this was the first group meeting following the winter break. The TI-Navigator exploration utilized a picture of a bridge as a background image in the Activity Center and required participants to enter an equation to match one or more of the bridge's arcs. The participants worked on and discussed this task for approximately 45 minutes of the session.

In the remaining portion of the two-hour session, I used the documents from Columbia University's Lesson Study Research Group Web site (http://www.tc.columbia.edu/lessonstudy) and workshop handouts and videos from the Lesson Study at Mills College Web site (http://www.lessonresearch.net/index.html) to support the participants in gaining a better perception of what is involved in lesson study. In addition, I asked the participants to focus on the four-column design to be used for thinking through and planning lessons. To gain a better picture of what the stages of lesson study would involve, participants watched video clips that

provided highlights of the planning stage, research lesson, and lesson analysis of the sample lesson "Can You Lift 100 Kg?" from the Lesson Study at Mills College Web site. I led the participants in a discussion about each stage of the lesson study cycle including the types of questions the teachers considered in planning the lesson and the observations they made in analyzing and revising the lesson. After the overview of lesson study, the teachers briefly discussed ideas of problem areas that they might consider for their lesson study. Amy, Carol, Dana, and Eric were present for this meeting.

Lesson Study Phase

After completing the professional development to prepare the teachers to engage in lesson study, the lesson study group began focusing on planning their research lesson. Stigler and Hiebert (1999) stated that to make significant progress in improving lessons, groups should be engaged in the lesson study for two uninterrupted hours per week. The participants planned to meet for two hours after school on Wednesdays. However, Wednesdays were also the days set aside for school faculty meetings when needed. As a result, the lesson study meeting time was shortened on two occasions. All of the lesson study planning meetings were conducted in Beth's classroom and were video recorded for analysis.

First lesson study planning meeting. During the first lesson study planning meeting, only Amy, Eric, and Gina were present. Gina was not present at the previous meeting where the participants learned about the stages of lesson study. To give her a brief overview of lesson study, I played the digital video disc (DVD) *Japanese Lesson Study: Ideas for Improving Mathematics Teaching* (Curcio & Billay, 2002), which introduced essential elements of lesson study. Amy volunteered to take notes on the planning meeting and was designated as the

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secretary for the group. These three participants spent time examining pacing guides and textbooks of the different subjects they taught to look for areas in their curriculum where they might integrate the use of the technology.

In addition, the participants in attendance examined the pacing guides of courses taught by other participants who were not present. With only half of the participants present, no final decisions were reached, however, regarding what topic of focus for the technology lesson. This first planning meeting lasted about one hour.

Second lesson study planning meeting. During the second group planning meeting, all participants except Eric were present. Because both the Algebra I and Algebra II classes were working with operations with polynomials and factoring, I distributed printed lesson ideas on these topics from NCTM's Illuminations Web site (http://illuminations.nctm.org/Lessons.aspx). I also supplied other resources such as *Navigating Through Geometry in grades 6 – 8* (Pugalee, Frykholm, Johnson, Slovin, Malloy, & Preston, 2002), *Navigating Through Geometry in grades 9 – 12* (Day, Kelley, Krussel, Lott, & Hirstein, 2001), *Navigating Through Algebra in grades 6 – 8* (Friel, Rachlin, & Doyle, 2001), *Navigating Through Algebra in grades 9 – 12* (Burke, Erickson, Lott, & Obert, 2001), *Navigating Through Measurement in grades 6 – 8* (Bright, Jordan, Malloy, & Watanabe, 2005), *Navigating Through Measurement in grades 9 – 12* (Albrecht, Burke, Ellis, Kennedy, & Maletsky, 2005), *Explorations in Algebra* (Dougherty, Matsumoto, & Zenigami, 2003), and *Algebra I: A Process Approach* (Rachlin, Matsumoto, Wada, & Doughterty, 2001) for the teachers to examine for lesson ideas. The group secretary informed the participants who had been absent from the previous meeting about the topics and

technology applications that were discussed in the first planning meeting. The group members suggested several possible ideas.

Through the discussion, the Algebra I teachers discussed areas of weakness from the common assessment that was given as the semester exam. They determined that they should go back and teach a review lesson to try to help their students develop a better understanding of the relationships of the slopes of parallel and perpendicular lines. The participants discussed several ideas about using slopes of parallel and perpendicular lines in a real-life context, but did not reach any conclusions about the order of the lesson. This meeting lasted the full two hours.

Third lesson study planning meeting. For the third group meeting, I was not present. I tried to reschedule for another day during that week, but there was no other day that all of the participants could meet at the same time. The participants asked if they could go ahead and meet without my being present as long as they video recorded everything. After conferring with my committee chairperson, I agreed to let them continue with their meeting. I sent my video camera to Gina, and she was responsible for making sure the session was video recorded. The principal called for a faculty meeting the same afternoon of the scheduled meeting, so the group meeting lasted only about one hour. All six participants were present for this group meeting.

Beth had talked with the other teachers prior to this meeting regarding the incorporation of information about the trucking industry into this lesson so that she could also meet a requirement for her graduate program of a video-recorded lesson based on a visit to an industry. The other teachers agreed. Amy, who was serving as the group secretary, and Beth took on leadership roles in conducting the meeting. During this meeting the group determined activities for a warm-up, the initial phase of the lesson. They also determined a task for the main part of

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the lesson. The goal of this task to allow students to discover the relationship of the slopes of parallel and perpendicular lines.

Fourth lesson planning meeting. During the fourth planning meeting, the group worked together to think through details for their lesson. All six participants were present for this two-hour meeting, although Eric was present for only the last hour. After a brief discussion of the flow of the lesson decided from the previous meeting, the group examined different maps that they might utilize for the lesson. The participants carefully considered issues related to content, pedagogy, and the technology to be used in compiling the details of the research lesson.

Review from university faculty member. Using the assessment design, LS-TPACK, described by Groth et al. (2009), I served as a mediator between the lesson study group and a university faculty member who agreed to provide feedback to the group about their plans. The university faculty member who reviewed the lesson plan was an experienced mathematics educator and mathematics teacher educator. She obtained her undergraduate degree, master's degree, and doctorate in mathematics education as well as a master's degree in applied mathematics. She planned and led summer professional development programs for four years with the goal of improving teachers' content and pedagogical knowledge. As part of this professional development, throughout the school year she worked with graduate students to plan and implement effective mathematics lessons in participating teachers' classes while groups of participating teachers observed. These model lessons were followed by debriefing sessions in which the participating teachers' discussions focused on student learning. In addition to these professional development sessions, she taught the mathematics methods course for preservice elementary teachers. As part of this course, she guided the preservice teachers in designing an

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instructional unit based on the Understanding by Design model (Wiggins & McTighe, 2005).

These experiences qualified this faculty member to give the participants in the lesson study

group guidance and feedback as they designed their research lesson.

Once the group was satisfied with their initial lesson plan, I emailed the plan to the

university faculty member for review. The following day, she provided feedback on the plans via

email for consideration by the group. She also gave a brief statement of her overall thoughts

about the lesson.

Lesson study meeting considering feedback from reviewer. The group members

agreed to meet on Friday afternoon to consider the feedback from the university faculty member,

so that the lesson could be taught the following week. All six of the participants were present for

this group meeting, which lasted about an hour and fifteen minutes. The lesson plans were not

very detailed and were typed in narrative form. Although, the participants had discussed details

in the previous meetings, they did not document these details in the plan. Prior to the meeting, I

created a blank four-column table, like the one in the template I had asked the participants to use

as a guide. I asked Amy to use the table to enter the details of the lesson, referencing the

template I had provided at the first meeting as a guide. I distributed copies of the printed lesson

plan that Amy had typed up during the group meetings along with the comments from the

university faculty member. I asked the participants to read through the lesson plan and the

reviewer comments before discussing the comments and possible changes to the lesson plan.

The participants discussed the suggested changes for the lesson plan and determined that

they had already discussed most of these issues, but had not documented their thoughts. Amy

entered the phases of the lesson into the table format along with time allocations, asking the

participants for input as she typed into the different columns. With more details in the table format, the group decided that Beth would teach the lesson on Wednesday of the following week to her third period Algebra I class. This class was selected because it was her smallest class. The group thought it would be easier to pilot the technology lesson with a smaller class.

At the conclusion of the session, I discussed observation guidelines outlined in the Lesson Study Protocol (Chokski et al., 2001). The participants selected roles to take as observers. Carol would record all of the teacher questions to the students, while Amy, Dana, and Eric would each record student interactions within one of the three groups. As the team leader, Gina was scheduled to attend a workshop on the day of the lesson and would not be able to observe the research lesson.

First research lesson. The first research lesson was taught by Beth to her third period Algebra I class of ten students on Wednesday, February 9, 2011. Prior to the lesson, I made arrangements with the administrator for substitute teachers to be in the other participants' classes during the research lesson so that the participants could observe the lesson. The area was under a winter weather warning with snow accumulations expected. An announcement was made early in the day that school would be dismissed at 1:00 due to the weather conditions expected to begin in the afternoon hours. As a result, the workshop that Gina was to attend was cancelled, and she was able to observe the research lesson.

During the lesson, Amy, Dana, and Eric each recorded student interactions within the groups. Carol recorded questions asked by the teacher and student. Gina recorded overall observances of the lesson as well as some student interactions of the group to which she was seated closest. I video recorded the lesson for analysis.

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First research lesson debrief. When school was dismissed, shortly after 1:00, the participants met to debrief regarding the research lesson. Because all members were present for the lesson and because time was limited due to weather conditions, the group began the discussion without watching the video. Due to a prior appointment and the fact that the after-school meeting was earlier than originally expected, Dana was not able to attend the debrief session. All other members were present for the debrief session. Amy recorded notes during the debrief session.

With the group seated in a circle, I asked Beth to begin the discussion, making comments about the context of the lesson, along with one strength and one area of improvement for the lesson. In accordance with the description given by Groth et al. (2009) in the LS-TPACK design and using the guidelines outlined in the lesson study protocol (Chokski et al., 2001), I asked that other members around the circle also describe a strength of the lesson and one area for improvement. I reminded the participants that the focus of the discussion should be on how to revise the lesson to improve students' learning, not the teacher's performance (Groth et al., 2009; Lewis, 2002).

Beth began the debrief session with comments about the lesson. Instead of following the format I had asked for, however, the conversation quickly turned to an open format with discussions about improvements that could be made. I attempted to move the discussion back to the desired format, but with the participants' excitement about wanting to discuss their observations and with the time restraint due to incoming weather conditions, I allowed the open-format discussion. I made certain, however, that every member of the group contributed to the discussion.

Due to the snow falling and starting to accumulate, I ended the discussion early. The debrief session lasted only about half an hour. The group agreed to meet again to make revisions to the lesson plan on Friday afternoon if school was in session that day.

Revisions to lesson plan. The group met after school on Friday following Wednesday's first research lesson and debrief to make revisions to the lesson plan. All six participants were present at this two-hour meeting. Carol agreed to teach the lesson to her Transition to Algebra class with Beth operating the computer for the TI-Navigator system. Carol informed the group of her students' prior knowledge. Changes were made to the lesson with considerations that these students were only recently learning about slope and had not been introduced to any relationships between the slopes of parallel or perpendicular lines. Several changes were also made to allow the technology-based lesson to flow more smoothly in the second lesson.

Second Research Lesson. Carol taught the revised research lesson to her second period Transition to Algebra students on Tuesday, February 15, 2011. Because Carol's projector was being repaired, Carol's class met in Beth's room. Beth operated the computer for the TI-Navigator system during the lesson. Amy recorded observation notes from interactions among students. Although the administrator agreed to make arrangements for substitute teachers, Dana, Eric, and Gina chose not to observe the second research lesson live because they were preparing their students for upcoming assessments.

Debrief of second research lesson. The group met to debrief the second research lesson after school the same day that the lesson was taught. Because Beth, Eric, and Gina were conducting after-school tutoring for their students, the debrief session was delayed. While waiting on tutoring sessions to end, Amy and I downloaded QuickTime to her computer so that

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the video would play properly. I prepared the video for viewing in Amy's classroom so that

Dana, Eric, and Gina could view the lesson before the debrief discussion. When Eric and Gina

finished their tutoring sessions, I played the video of the second debrief lesson. I asked the

participants to record observer's notes as they viewed the video. Although I asked the

participants not to discuss the lesson during the video, they still had some discussion during the

viewing of the video.

After the video, I reminded the participants about the format for debriefing the lesson. I

asked Carol to begin the discussion by describing one strength from the lesson and one area of

improvement with other group members to follow. I also reminded the group members that the

discussion should focus on student learning, not on the teacher.

Following the lesson debrief, the participants completed the second writing prompt

(Appendix F), to serve as an additional means of documenting their TPACK development

through the lesson study process. The writing prompt asked the participants to reflect on the

aspects of the lesson study process and rate the effectiveness of the components in shaping their

thoughts and beliefs about effective technology integration in a mathematics classroom. In

addition the participants described their thoughts and beliefs about effective technology

integration in a mathematics classroom and how their beliefs related to the components of the

lesson study process. This writing prompt was designed to show the aspects of the lesson study

that the participants perceive as important in facilitating their TPACK development.

Final Phase

At the end of the debrief session of the second research lesson, I asked participants to

sign up for times during the following two weeks for post-classroom observations and post-

interviews. The purpose of these post-observations and post-interviews was to document changes in the participants' beliefs and practices concerning technology use. Some participants expressed concern for not being able to plan a "good" technology lesson with the content topics in the upcoming plans. I informed the participants that I did not want them to plan a "show" as a lesson, but that I wanted to see how they used technology on a regular basis. I completed all of the post-classroom observations and post-interviews within two weeks of the completion of the lesson study.

Originally, I had planned to conduct delayed classroom observations and interviews after a month to compare to initial- and post-observations and interviews to note changes that might have been superficial and those that might be lasting. The timing of these delayed observations and interviews, however, would have been after spring break. The time after spring break is usually designated for a strong focus on preparing for state assessments. Therefore, because these observations would be representative of teaching to the test rather than regular classroom instruction, my committee chairperson and I decided that data from delayed observations would not be reliable and that delayed interviews would not be necessary.

<center>**Data Analysis**</center>

All of the qualitative data gathered throughout the study was analyzed using reflective analysis, "a process in which the researcher relies primarily on intuition and judgment in order to portray or evaluate the phenomenon being studied" (Gall et al., 2007, p. 472). I transcribed all of the initial interviews and lesson study group meeting conversations for analysis. In the transcriptions, I made notes of non-verbal language such as gestures or long pauses. I paid a

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transcriber to transcribe the post interviews. After all data was gathered, for the reflective analysis, I carefully examined and re-examined all of the data collected (Gall et al., 2007).

To answer the first research question, I used reflective analysis. Using the TPACK developmental model proposed by Niess et al. (2009) as a lens, I reflected on transcripts of initial interviews, notes from initial classroom observations, and initial surveys to determine participants' beginning TPACK stages. I analyzed writing prompts, transcripts of video recordings of group meetings, notes from post-observations, and transcripts from post-interviews to document changes, if any, in the TPACK of each participant through the lesson study process. I also analyzed transcripts from the group meetings for evidence of the stages of TPACK development within group interactions.

To address the second research question, I analyzed data about the participants' educational backgrounds and technological backgrounds from the Survey of Technology Use and Educational Background (see Appendix A), notes from initial classroom observation, and transcripts of initial interviews. I examined the findings from the first research question and the participants' backgrounds, noting trends that emerged in the progression through the TPACK stages for participants based on prior experiences with technology.

For the third research question, I referred to participants' responses to the writing prompts to determine which experiences they felt were helpful in shaping their thinking about effective technology integration. I also referred to interview transcripts for input regarding the supports the participants felt were necessary to help facilitate their effective use of technology and thus their TPACK development.

Because I implemented "backyard research" (Cresswell, 2009, p. 177), I utilized several strategies to strengthen the validity of my data analysis. I used researcher reflection, peer examination, a credible critic, and member checking to verify findings. Researcher reflection refers to a sensitivity of the researcher when relating to the situation being studied. As part of this researcher reflection, I clearly defined and documented the role relationships and assumptions that I had during the study (Gall et al., 2007). I kept a researcher journal for these reflections. Peer examination refers to asking "colleagues to comment on the findings as they emerge and to review a draft of the case study report" (Gall et al., 2007, p. 476). In instances where I thought bias may have entered my analysis or the level of TPACK development was not clear, I sought a peer review from my colleague who was also studying inservice teachers' TPACK development and worked with me in designing the TPACK Self-Report Survey, interview protocol, and observation protocol. Dr. Margaret Niess, lead author of the article that introduced the TPACK Development Model, served as a credible critic to verify my final analyses. Member checking refers to asking participants to review statements in the report for accuracy and completeness (Gall et al., 2007). I asked participants to review quotes that were to be used for accuracy. I also asked the participants who were highlighted as case studies to review descriptions of their classroom observations for accuracy and completeness.

Limitations and Delimitations

The purposeful selection and prior relationship of participants and the researcher present limitations to the study. Participants were inservice Algebra I teachers who were involved in the 2008 – 2010 study with which I previously assisted. I also taught with five of the participants during my teaching career. I anticipated that my established relationship with these teachers

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would not only provide entry to the research site but also promote a trust that would allow openness and honesty throughout the study. As I served the dual role of facilitator of the professional development and researcher, however, with the researcher serving as the main instrument and reflective analysis as the method of data analysis, some bias may have influenced my conclusions. Peer examination of questionable analyses from the colleague who was also studying TPACK development served to minimize possible biases.

Other instruments of this study present potential limitations. The Survey of Technology Use and Educational Background and writing prompts were researcher-designed and had not been used in any other studies. Although they were peer-reviewed by the colleague mentioned earlier and revisions were made based on her comments, these instruments had not been used previously. The same was true of the observation protocol and interview protocol. The TPACK Development Model Self-Report Survey was also designed in collaboration with the colleague. A credible critic, Dr. Margaret Niess, reviewed this survey and changes were made on the survey based on her recommendations. None of these instruments, however, had been used previously. There is, therefore, no information regarding the reliability of these instruments, which could pose a limitation to the study.

Additionally, data from the surveys, interviews, and writing prompts were self-reported by the participants. Research indicates that self-reported data is often biased (Ivy, 2011; Kopcha & Sullivan, 2006; McCrory, 2010). Classroom observations, the group lesson plan, and videos from group meetings and research lessons, however, provided practice-related data that balanced possible self-report biases.

Due to the qualitative nature of this study and the small number of participants, the findings are not generalizable, a delimitation of the study. Although not generalizable to larger populations, this study serves to share the experiences of the participants, to inform future TPACK research, and to address questions previously posed by other researchers. The reader may determine transferability to similar cases based on the thorough description of the participants and methods of this study (Patton, 2002).

Summary

These case studies provided a means to examine how participating in a technology-based lesson study impacts inservice teachers' TPACK, how teachers' progression through the stages of TPACK development compares with respect to their educational and technological backgrounds and experiences, and what supports teachers perceive as important in facilitating TPACK development. The surveys, observation and interview protocols, and writing prompts gathered information to allow for thick description in describing the participants' experiences. The phases of the study were intended for gathering initial data, providing opportunities for experiences in learning with the technology and practice in thinking about students' thinking in observation and analyses of a technology lesson, informing participants about lesson study, engaging the participants in the lesson study process, and gathering post data. Data gathered from the surveys, observations, interviews, writing prompts, videos of group meetings and research lessons, and the group lesson plan were analyzed by reflective analysis through the lens of the TPACK development model (Niess et al., 2009). The thick descriptions of the participants' experiences and changes in TPACK levels serve to inform research on mathematics teachers' TPACK development.

CHAPTER IV: FINDINGS

Introduction

Technological, pedagogical, and content knowledge (TPACK) is the intersection of teachers' knowledge of technology, pedagogy, and content (Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). After examining TPACK research and consulting with leaders in the field, Cox (2008) proposed the following working definition of TPACK: "Technological pedagogical content knowledge is a way of thinking about the complex relationships between technology, pedagogy, and content in a specific context which is represented through the carefully considered implementation of technology in a classroom setting in order to help students better understand a particular topic" (pps. 50-51). TPACK research has revealed that practices such as collaboratively planning technology lessons, observing technology lessons with a focus on students' learning, and analyzing strengths and weaknesses of technology lessons serve to promote teachers' TPACK (Cavin, 2007; Lee & Hollebrands, 2008; Richardson, 2009). Niess et al. (2009) proposed the TPACK Development Model that described levels through which mathematics teachers progress as their TPACK develops for a given technology. According to this model, teachers with a developed PCK progress through the stages of recognizing, accepting, adapting, exploring, and advancing as they incorporate a given technology in their instructional practices. The more advanced levels of the TPACK Development Model include the practices of planning, implementing, and reflecting on technology lessons with concern for promoting students' thinking and understanding of mathematics. These practices are major

components of the practice of lesson study, a professional development model with a focus of improving teachers' instruction and students' learning

This study examined secondary mathematics teachers' TPACK development through participation in a technology-based lesson study. I used the TPACK Development Model (Niess et al., 2009) as a lens to analyze the data gathered in this qualitative layered case study. The TPACK development model is divided into four major themes: curriculum and assessment, learning, teaching, and access. Each of these four themes is divided into five levels: recognizing, accepting, adapting, exploring, and advancing. In my reflective analysis, I looked for evidence of TPACK development based on the descriptors of these five stages. I employed peer evaluation to verify my analysis of the data.

This chapter describes the findings of the study and how those findings relate to the three research questions:

1. How does participating in lesson study emphasizing the use of TI-84 graphing calculators and the TI-Navigator system impact secondary mathematics teachers' TPACK?

2. How do teachers' progression through the stages of TPACK development compare with respect to their educational and technological backgrounds and experiences?

3. What supports do secondary mathematics teachers perceive as important in facilitating TPACK development?

To address the first research question, the paragraphs that follow describe in detail the whole-group interactions and the levels of TPACK indicated by those interactions. Individual cases of the four participants who had the TI-Navigator system will also be discussed. These cases will be followed by paragraphs that address the second and third research questions.

TPACK Through Technology-based Lesson Study

As in any lesson study, involvement in the technology-based lesson study required that the participants examine their curriculum, reflect on students' knowledge, plan a lesson to promote student thinking, teach/observe the lesson, reflect on the lesson by making revisions to improve the impact on students' understanding, teach/observe the revised lesson, and again reflect on the lesson by making revisions that might improve students' learning. During this technology-based lesson study, the participants determined an area within the curriculum to design a lesson utilizing the TI-84 graphing calculators and the TI-Navigator system. In designing the lesson, participants reflected on students' prior knowledge and discussed ways they could plan a lesson that would utilize the technology to engage the students in thinking about the mathematical concepts. After the initial lesson, they reflected on the lesson, with a focus on students' learning, and made revisions to enhance students' understanding further through the integration of the technology. The participants revised the lesson based on their observations. After the second lesson, they again reflected on the lesson with a focus on students' learning and made revisions that might enhance students' understanding through technology integration.

The following paragraphs describe the whole-group interactions that occurred during the lesson study meetings. The TPACK development levels indicated by these interactions are also discussed. Individual cases of TPACK development of the four participants who had TI-Navigator systems follow the discussion of whole-group interactions.

Whole-group TPACK Development

During the technology-based lesson study, the participants worked collaboratively in searching the curriculum and planning a lesson that utilized the TI-84 graphing calculators and TI-Navigator system to promote students' understanding. The following paragraphs describe details of each group meeting including evidence of TPACK development. I documented evidence from levels of TPACK development for three of the four major themes in the whole-group interactions: curriculum and assessment, learning, and teaching. Because the whole group interactions were not in a classroom setting, the access theme was not evidenced.

First lesson study planning meeting. During this initial planning meeting, only half of the participants were present. Amy, Eric, and Gina searched through topics in their curriculum looking for areas where the technology could be used to develop students' understanding of the mathematics. They searched through their books, pacing guides, and online sources seeking ideas and strategies for implementing the technology.

Amy posed a question to the group about how to use the technology to allow her geometry students to gain a better understanding of the trigonometric ratios in right triangles. Amy and Gina explored the Cabri Jr. application on the TI-84 calculators for possible implementation in a geometry lesson. Amy expressed a desire to learn more about how to effectively incorporate the Cabri Jr. application in her geometry lessons.

> I'll say this. One thing I would like to use more and I would LOVE to know all how it
> works and what not, is that Cabri Jr. But I have no idea about it. And, I've only messed
> with it a couple of times. I don't know anything about it. I don't even know how to draw
> a line. (Gina expressed that she thought Cabri Jr. was a game.) It's supposed to be a

geometry-type thing, and I just don't know how to do it. But, I mean that would be good

with the [TI-]Navigators with the snapshots to see what the different students come up

with, if I could understand myself how to do it.

After exploring the capabilities of Cabri Jr., Amy said:

Ok, this is what I was trying to do, and it actually let me in Cabri Jr. You know how you

were saying get a triangle, find all of the different ratios that you can? You can actually

do that in [Cabri Jr.]. So, like I just said 4.0 divided by [another side of the triangle] and

got one ratio. Then I could go and do the other one.

After a few moments, Amy considered uses for the technology in her class.

Let's say we could do a screen capture and practice getting the different ratios, labeling

what's opposite, what's adjacent, what's the hypotenuse if you have it. (Eric and Gina

make some comments about their textbook.) Ooh, we can find the angle measure, too, in

Cabri Jr. I could use this! That's SO COOL!

After a few more moments of sharing what she was exploring, Amy inserted:

I mean with that 45-45-90 might come up, and 30-60-90 might come up with their

different ratios. If some of my students have the same [ratios], we can make that

connection.

Amy continued searching for technology ideas to implement in her lessons on

trigonometric ratios. She performed an Internet search on her cellular device and found several

tasks in which she was interested. Amy exemplified elements of the exploring level of TPACK

development for the curriculum and assessment theme through her search for ideas and strategies

to implement the technology to develop the mathematics that her students would be learning. For

the learning theme, Amy demonstrated elements of the adapting level of TPACK development in beginning to explore and experiment with integrating the technology as a learning tool.

Eric also displayed TPACK during this initial lesson study meeting. Early in the first meeting, Eric referenced the task from a previous professional development session in which the participants matched the curves of an image contained in the Activity Center of the TI-Navigator system. With regard to working with his pre-calculus students, Eric considered similar lesson ideas.

I could skip over to the family of graphs and do something similar to what we did last week to try to show [the students] how the change in the equation of the parent graph is going to change the graph.

After a few moments, Eric added:

Well, like the one we did last week, we could get them to pair a graph of the quadratic function, and kind of let them change the equation to see what happens as they change the equation.

The thinking revealed through these comments implied Eric's accepting of the technology. His desire to mimic the activity from the professional development session indicated that Eric was thinking on the accepting level of TPACK development for the teaching theme.

Later in the session, after searching quietly through his curriculum and textbooks, Eric looked up pensively and stated:

What about squaring a binomial? You think maybe we could do something with that? Some kind of way to, well maybe them go through it, a few of them, and get the answers,

and then examine to come up with the rules for squaring a binomial mentally without

going through all the FOIL.

Eric exemplified elements of the exploring level of TPACK for the curriculum and assessment

theme as he continued searching for ways to implement the technology to allow students to

develop the understanding of squaring a binomial. After more searching through his book, Eric

shared another lesson idea.

I've got a graphing calculator exploration here in the book where you explore and then

make conjectures about the sum, difference, product, and quotient of two functions after

you have graphed them and done them on the calculator. Then you go back and make

conjectures about them.

This exploration involved using Y-vars and graphing functions of the TI-84 calculators to

explore operations with polynomial functions. Eric and Amy worked through the exploration

together while Gina continued exploring Cabri Jr. The three participants demonstrated elements

of the adapting level of TPACK for the learning theme in their own exploration and

experimentation of the technology as mathematics learning tools.

The task of planning a technology-based lesson with the goal of enhancing students'

understanding engaged the participants in seeking ideas and strategies for technology

implementation that they had not utilized before. The actions of the participants during this

session included elements of the exploring level of TPACK development in examining their

curriculum. Their own explorations in using the technology as a learning tool exemplified

elements of the adapting level of TPACK development for the learning theme. The participants'

ideas of implementing the technology in their own teaching indicated elements of the accepting level of TPACK development for the teaching theme.

Second lesson study planning meeting. For the second lesson planning meeting, all of the participants except Eric were present. Carol started the meeting by excitedly sharing her students' first experience with the TI-Navigator system after returning from a long weekend with a snow day and the Martin Luther King, Jr., holiday.

> Guess what I did last week! So, we had the snow days, you know. So, I thought, "Ok, this would be the perfect time because we're not close to exams. I pulled out the TI-Navigator. . . . They had a ball! . . . I had [the students plot points to form] a diagonal line. And I said, "Ok, somebody try to draw a line that would go through as many of our [points] as possible." So, we were actually using it the very first time we did it.

Carol's description of her experimental use of the TI-Navigator system during the short week of classes implied that she was at the accepting level of TPACK development for the teaching theme. Although the activities Carol described related to topics she had previously taught in class, the purpose of this technology use was to allow time for her students and herself to practice in utilizing the capabilities of the technology. She did not have a particular mathematical learning goal for this lesson.

After some discussion about possible topics to focus on for preparing the research lesson, the participants decided to refer back to problem areas from the Algebra I semester exam, which was designed with problems that would be similar to those that students might see on the end-of-the-year Algebra I state assessment. The participants decided that the concept of the relationships of the slopes of parallel and perpendicular lines was an area in which the students needed to gain

a better understanding. The participants also discussed that students did not have a clear understanding of the concept of slope. Below is an excerpt of dialogue among the participants as they discussed how to use the technology to help students better understand the concept of slope and the relationships of the slopes of parallel and perpendicular lines.

Gina: And, [slope] needs to be taught as the rate of change, because that's the way it's worded on state test. They hardly ever use the word slope on the state test. It's usually rate of change.

Carol: I'm really trying to push that this year in transitions after seeing it so much last year. . . . So, yeah, rate of change.

Amy: Ok, so do we think that it would be good, especially since we have the great SMART Board and the great TI-Navigator [and] calculators, to do something in the sense of showing the kids like a house and having the roof and saying that this is the slope of the roof? Or having a mountain and showing them that, like somebody sledding down?

Dana: So, instead of just lines on a graph which are abstract and non-related?

Amy: You know, whenever I think about slope, I always think about somebody having to run uphill or run downhill. Would that help make the connection? Get like pictures?

Beth: Climbing stairs.

Dana: Well, different things.

Later in the session, the conversation returned to the discussion of how to use the technology to emphasize the concept of slope.

Amy: I think a lot of it [is] they just can't visualize [slope] without pictures.

Beth: Yeah, I think it would be good to do the background picture, especially because they already know about equations. Once they know about equations and stuff, which they already do, putting a picture of a mountain on there and trying to get them to write an equation.

Amy: Well, see, I'm even thinking about motion-type animation . . . I'm sure there's somewhere online where you could actually manipulate the mountain and then the rider slides down. Did he go faster? You know, to show the time of it. What happened? Why would he go faster? Something of that nature.

Beth: You know they have virtual things like that.

Amy: I mean do y'all think that would be a good way to introduce it? To actually see maybe a person sliding and see his rate going faster?

Dana: And, then that way they get the idea of rate of change, of position.

The participants' discussion demonstrates knowledge of the content of slope along with knowledge of their students and how their students learn. The conversation also displays their desire to implement the technology with the content and pedagogical knowledge, thus further developing their TPACK. This group conversation exemplified the adapting level of TPACK development for the curriculum and assessment themes because the participants acknowledged some benefits of incorporating the technology in developing a lesson to reinforce the concept of a targeted topic, namely slope. The participants beginning to explore and practice integrating the technology as a learning tool demonstrated elements of the adapting level of TPACK

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development for the learning theme. The decision to revisit a concept that had been previously taught implied the adapting level of TPACK development for the teaching theme.

Further in the discussion, Dana expressed her belief that the fact that angles formed by perpendicular lines measure 90 degrees should be emphasized. Amy suggested that they could use the Cabri Jr. application and lead students through the directions to form perpendicular lines. She also recommended using the screen capture feature of the TI-Navigator to show all of the students' lines. Then the students could measure the angles and the slopes to generalize the relationships. Amy's idea to lead the students in the discovery exemplified elements of the adapting level of TPACK development for the learning and teaching themes.

Third lesson study planning meeting. Prior to the third lesson study planning meeting, Beth talked with the other participants about incorporating information from the trucking industry into the research lesson so that she could also meet a requirement for her graduate program of teaching and video-recording a lesson based on a visit to an industry. Beth shared with the group the information she had concerning the trucking industry that was related to parallel and perpendicular lines. Then the group further discussed the design of the lesson. The participants discussed various ideas and determined a plan for the initial phase of the lesson. Then the participants focused on how to present the lesson so that the students could discover the concept of the relationships of the slopes of parallel and perpendicular lines.

As a carryover from the previous week's discussion, the idea of placing a background image in the Activity Center of the TI-Navigator system pervaded the discussion. Related to the trucking theme, the participants discussed the possibility of using a map that contained parallel and perpendicular streets. Beth was not present at the professional development session that

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included an image in the Activity Center, but she had participated in a similar task as part of the TI-Navigator professional development sessions during the 2008 – 2010 study. The dialogue below occurred as the participants were discussing how to incorporate the map using the technology.

Dana: Have them understand from the pictures, "Oh, these lines don't intersect." And, then have them look at the equations of the lines, because they know how to do equations of the individual lines, and then to discover that [for] the parallel lines the slopes are the same.

Beth: Yeah, I like that so much better.

Dana: And then you say, "Ok, let's look at some other lines and their slopes and see if there's another kind of line that has a special relationship like parallel lines do." But, then you have to prove that [the angles formed by the lines are] right angles. I don't like this idea of they're right angles because the slopes. . .

The conversation veered to ways to verify that the angles formed were right angles and then continued as follows:

Amy: Could we not use the city streets to get the students to write equations and then realize then like their slopes have to be the same because they're parallel?

Dana: Right, right.

Beth: Oh, we can use that as the background. Yes! I like that! But, I don't remember how to do it.

Gina suggested that she had some materials from a workshop she had recently attended. She left the room to get her materials. A few moments later the conversation about using a street map resumed.

Dana: I do like that. If you have the kids write the equations for the lines up there, and then you look at the slopes, and then [ask] which slopes go with which lines, and then again, you'd see the parallel stand out real quick.

Beth: Oh, yeah.

Dana: You know, but would they see the relationship? They're not going to see that relationship as quickly [with] the perpendicular.

Amy: Well, not necessarily go for it as perpendicular. I'm listening. Like you said number the streets or have the street names on them and then [assign a street to] each group, if we're still in groups. You say, "You find the equation for this line. You find the equation for this line. You do this one." And then when we look at it, if they got [the equations], then we can say, "Well, what's the slope?"

Dana: Right, right.

Beth: (Trying to import background image) I don't remember how to do this.

Dana: And can you? Maybe if you could graph on top of that map, right? And, then their equations for their lines [would be] on top, so they can see if they actually got the right [equations]. And, then you can look at the slopes.

Amy: Yeah, you can. Yeah. And if we could get a good city map, we could do intersecting and perpendicular.

Dana: And then take out her big protractor. Take out her big protractor and make sure they are 90 degree [angles].

Most of the group seemed to like this idea. Gina, who was also absent for the professional development session that utilized a background image in the Activity Center of the TI-Navigator, searched for "better" lesson ideas in materials she had received from a recent workshop. Although the group liked some of the ideas from the workshop materials, the discussion returned to the idea of a using an image of a map with parallel and perpendicular streets.

The group discussed several content issues for consideration in choosing a map that would provide students the opportunity to discover the relationship of the slopes of parallel lines and perpendicular lines. Although participants had previously discussed that students had trouble understanding horizontal and vertical lines as well as their slopes, they decided that they did not want to present horizontal and vertical lines for this particular lesson. They wanted the students to notice a relationship of opposite reciprocal slopes for perpendicular lines and felt that horizontal and vertical lines would not work since vertical lines have an undefined slope. They also discussed what fractions would be easier for the students to recognize opposite reciprocals. They decided that they should not use integers and their reciprocals. The participants thought that students might not recognize those as reciprocals. They decided they should use non-integer rational numbers.

They also considered whether to use a map of a familiar area or somewhere the students might not have visited previously. Beth downloaded a map of Memphis for display, but the participants felt it was too big. Beth suggested that she could focus on a smaller region of the map, but Gina recommended that using a local map would be more meaningful to the students.

Beth displayed a map of streets around the school. Some of the streets appeared to be parallel or perpendicular, but most of them were vertical or horizontal, the type that the participants had determined they should avoid for this discovery. They found two streets on the local map that were not vertical or horizontal, but the participants did not try to match the streets with equations during this meeting.

The participants continued to discuss the pedagogy in implementing the map task. They decided they would assign different streets to different groups for students to find equations that would best represent the streets. Then during a whole group discussion and through questioning about the similarities of the equations, the students would be able to recognize the pattern of the slopes of the parallel lines being the same and the slopes of the perpendicular lines being opposite reciprocals. The session ended with the following dialogue.

Dana: Yeah, write the equations for the lines and then discover that the lines for the parallel roads have the same slopes, right? And then look at the (interrupted by Beth)

Beth: How are we going to lead them in to that?

Dana: Well, they should - just have them look at it.

Beth: Would we then, like after they got these two, say, "Ok, well let's look at this," because I can change [the view] from just graph to graph/equation.

Dana: Well, you could say something about, "Which of these equations? Look at these equations, just the equations themselves. Which of the equations have the same slopes?"

Beth: All right, see I can do graph here, and then I can do graph/equation where the equation is out [to the side].

Dana: And then just say, "Which of the equations have the same slopes?" Well, this and this. And then go back and say, "Well, which of these lines did those represent?"

Beth: You don't have to say that. You can say, "What do they have in common?"

Dana: What do they have in common? Right. And then say, "Well, let's go back and look at the streets that these equations are." And, then at that point they'll see because they have the same slopes, [the lines] are also parallel. "Does this happen all of the time?"

The considerations the participants discussed related to using the technology with sound pedagogical practices to promote student exploration of the content. The participants planned the lesson to allow the students to explore and discover the relationships of the slopes of parallel and perpendicular lines. The teacher role would be that of facilitator, guiding not directing the exploration. This lesson plan represented elements of the exploring level of the TPACK Development Model for the learning theme. There are two pieces of evidence, however, to indicate that the lesson exemplified the adapting level of TPACK development for the teaching theme. First, this lesson was designed to reinforce a previously taught concept. Second, the map task was an adaptation of the map task from the video of the lesson that the participants watched and the bridge task in which the participants engaged during the Teachers as Learners phase.

Fourth lesson study planning meeting. The fourth lesson study planning meeting began with a discussion about content and pedagogical issues to consider in selecting the map to utilize

as the background image. The dialogue below occurred at the beginning of the meeting, following a brief overview of the decisions from the previous meeting.

Dana: Because we had the graph up there and we were looking at the streets and trying to figure out which ones were perpendicular, right?

Amy: Yeah.

Dana: And then it was how do you get them to notice that the slopes, because that's when you got the protractor out and you were like, "Are the map lines really going to be perpendicular? Ninety degrees?" And then will they notice that the slopes are opposite reciprocals? 'Cause you almost have to set that up. Well, you have to have them exact to begin with, right?

Amy: What do you mean exact? Like they would have to find the exact equation? Is that what you mean?

Dana: Well, they would have to be exactly perpendicular. All of the street lines, you know, might not be . . . then they'd have slopes that you could easily find on the graph.

Carol: We were going to have them use the TI-Navigator to try to match the slopes, right? Is that what you said?

Dana: Right, right.

Amy: Mmm-hmm, with the city graph that we had up there that we picked out.

Dana: But, I don't know. I mean surely they'll see that. I mean if they can write the slopes as fractions, yeah.

Gina: Well, they all know what right angles are.

Dana: Right. And that was another one. Do you take it at face value? Do you take it at face value when the teacher says, "This is a right angle"? You know they form a right angle. Yeah, yeah, sure they do.

Gina: Well, it may not be. It may be 88 degrees, but they know basically what a right angle is supposed to look like.

Dana: I know. What a right angle is - you['re] assuming.

Amy: 88 degrees is not a right angle.

(Amy and Carol laugh.)

Gina: I know it. I'm saying up there on that map, up there on the map. Y'all are not listening to what I'm saying.

Amy: You said, "Up there on the map." I'm listening.

Beth: Something about, all I heard was something about 88 degrees.

Carol: (laughs)

Gina: They're not going to be exactly 90 degrees on a lot of it. But, it may look perpendicular. It may be off a little bit, is what I was saying.

Amy: (to Beth) Could we? Remember when you made [the zoom] square? Could that? Does that go with the picture background as well? Or does the picture stay the same?

Beth: I bet it stays the same.

Dana: If you put a whole bunch of equations of lines up there, right? Now they're going to pick out the parallel fairly quickly if you put it in slope-intercept form. I mean

they'll notice right off the bat that [the slopes] are the same, right? Even if they're

not reduced fractions, you think they'd pick those up?

Carol: Right.

Dana: $\frac{3}{6}$ and $\frac{2}{4}$ and $\frac{1}{2}$. They would notice that they were the same?

Amy: Well, if they didn't we would tell them.

Dana: If they didn't, yeah, ok. But then do you think they'd notice opposite reciprocals

fairly easily? That would be a little more difficult. But, like the equation for a line

is $2x$ and write another equation for a line, it's $-\left(\frac{1}{2}\right)x$. I mean I guess you'd

have to (interrupted by Amy)

Amy: I don't know if they'd see it quickly.

Dana: Ok, if you showed a couple of perpendicular lines . . . Show a couple of

perpendicular lines and their slopes. Then you show another set of perpendicular

lines and their slopes. Then you show another set of perpendicular lines and their

slopes. You know? Eventually, it would sink in. Don't you think? Do you notice

anything there?

Amy: Right.

Dana: Because I think somebody said start off with things like $\frac{3}{5}$ and $-\frac{5}{3}$. Don't start

off with just numbers and their reciprocals.

Carol: Like 2. Don't start off with that.

The participants' content and pedagogical considerations in selecting an appropriate map demonstrated their "concern for guiding students in understanding" (Niess et al., 2009, p. 21) the mathematics as a focus of their planning and exemplified the exploring level of TPACK development for the learning theme. The TPACK development level for the teaching theme was adapting for the mathematics learning, instructional, and professional development descriptors. The inductive nature of the investigation described by Dana of examining different pairs of perpendicular lines before making a generalization about their slopes indicated the TPACK development level for the environment descriptor of the teaching theme was exploring.

The majority of this session was spent examining and testing different maps to use for the exploration task. The participants looked at four different maps, trying to match the streets with equations before deciding upon a map to use for the lesson. Maps that were eliminated presented issues such as streets with slopes that were represented as an integer and the opposite reciprocal, streets with zero and undefined slopes, streets with slopes that would be difficult for the students to find on the map, and streets that appeared perpendicular but were not matched with perpendicular lines.

The group decided that the window settings of the graph should display a "square" view so that the perpendicular lines would appear to form right angles. Beth, who controlled the computer and display during the meeting, changed the window settings on the TI-Navigator Activity Center graph and changed the display area of the map to create a map and grid overlay where the streets would pass closer to integer or half-integer coordinate values to make the graph easier to interpret. This change allowed the focus to be on discovering the relationship of the slopes of the parallel and perpendicular lines, not on estimating coordinate values from the

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graph. The group found equations to represent six streets: three parallel streets and three streets

perpendicular to the three parallel streets. The class selected for the first lesson would have three

groups, so the teacher would assign two streets for each group to match with an equation. The

two streets assigned would be perpendicular to each other and parallel to streets assigned to other

groups.

As the participants were having difficulty finding equations to closely match the streets

on the different maps, several participants expressed concern that the students might not submit

equations that would lead to the students' discovery of the relationship of the slopes of parallel

and perpendicular lines. The participants recognized that the width of the streets represented on

the map would allow the students to submit equations of lines that would be on the street,

although the equations might not be exactly the same as those the participants predicted to best

align with the street. Some participants even expressed concern that the map might overwhelm

the students. The dialogue below, which occurred after the participants worked to submit linear

equations to overlay the streets on the displayed map, demonstrates these concerns.

Beth: All right. Here's my thing. What are we going to do if they don't create those
lines?

Dana: (laugh) They put in $y = 3$.

Beth: Or, if they create these lines and they don't have opposite reciprocal slopes?

Dana: Like if they just don't get it or if really the equation? Yeah, right. They write the
equation for the lines and they really don't have - ok.

Beth: Like with this (points to the map on the screen).

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Amy: Well, I just think that depends on what picture you have. . . . you've got to get a really good picture to go with it.

Beth: Yeah.

Amy: I mean because your graph is square, true enough, so any picture that would line up with that graph, realistically would be good. The picture isn't square.

Dana: Because, I mean like would you call those two close enough? Would you call those streets perpendicular? Or, I mean would you call that line (interrupted by Gina)

Gina: (sarcastically, because others laughed at her suggestion earlier that the angles may be 88 degrees) No, they've got to be exactly 90.

Amy: And the green lines are 90. (The green lines represent the linear equations submitted by the participants.)

Dana: But, that is exactly 90. The green ones are exactly 90.

Gina: But, the streets aren't.

Dana: That's what I'm saying. But would you call those lines close enough to what those streets are to say that they are perpendicular? And would the kids come up with the equations that were perpendicular? Would the kids have come up with the same equations I did for those streets? Would there be another one that would fit better? That weren't, weren't opposite reciprocals? Does that make sense?

Amy: Mmm-hmm.

Dana: I mean do you think they'd come up with something else?

Carol: Let's try it again.

The participants' concern over the students not submitting the same equations as those anticipated implied their desire to design a lesson that would guide the students' understanding and indicated elements of the exploring level of TPACK development for the learning theme. Despite these concerns, the group decided that they would try the exploration and observe the equations that students would submit. The group determined that the lesson plan was complete.

First research lesson debrief. The group met the afternoon of the first research lesson to reflect on the lesson taught by Beth. The comments below represent some of the participants' reflections on the first research lesson. These comments are in the same order as they occurred in the conversation, but did not all occur successively.

Beth: I thought [the lesson] went fairly decent. I think it took them a little while to catch on. It took them a little longer than I thought it would for them to catch on how to get the - I noticed the group that [Carol was] with, they were getting two points to find the slope between them. I found that odd because [a student] was [at the board] the whole time.

Amy: I think it would have been better if we would have worked a problem with them. Like your first problem was a graph, and we just asked them, "What was the slope?" Why didn't we take it to the next thing and say, "What's the equation?" You know, not just say, "What's the slope?" but, "What is the equation?" Get them on that y-axis and talk about that. And then, I think we could have done another problem, especially now seeing that they wanted [not to] do fractions at all. Give them another one that's not zero or one. You know give them something where they kinda have to make up what the y-intercept is. So basically, another

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graph, especially since that was what we were focusing on today was graphs and graphing.

Carol: Because toward the end what I was thinking is, "Ok, our goal is parallel and perpendicular. We're not gonna get there." So, I think I said to [Gina], I said, "Maybe we should start guiding them to get to the…"

Beth: Well, they had their street, like the lines that, I mean [the lines] did work with the streets, but they weren't perpendicular. And I just said, "Look at your two streets." I was like, "You're doing all right, but you can get a little closer." I said, "Look at your two streets." And they looked at them and I said, "What do you notice about them? How are they related?" And they said, "(Gasp of realization) They're perpendicular." And I said, "Well, do your equations show that they're perpendicular?" She said, "No." So they talked, and then they changed it.

Carol: Because my group had an "AHA" moment because as soon as they saw [the slopes of another group's lines were opposite reciprocals], they were looking and she pointed out the perpendicular lines, and I said, "Look at how they're different." And they went, (big gasp of realization). And I said, "Now change your other line." So, if we would have had 10 more minutes, then the focus would have been achieved better, because they got it then. They did the (big gasp of realization).

Beth: I think one is like she was saying. Go over, kinda review like how to write an equation.

Amy: That's important, because my kids wouldn't move the *y*, the *b*, at all, the *y*-intercept.

Beth: Yeah, because I think that they were unsure at first like, "I don't remember how to write an equation. I mean I know I have $y = mx + b$," but they just couldn't remember what to do, what to plug in where. And, I really think at first they were really - I mean that class in particular is scared to get something wrong, and so they were like, "I don't want to type an equation in and it be wrong." You know? But once they typed it in and could see it and see how they needed to change it some, they weren't as scared.

Carol: The moment that the map went up there and they were told to do a line on their roads, or however it was presented, they all kinda stopped for a minute, you know? And I was wondering if maybe we could have picked a road that was not assigned to them and just say, "I want you to look at this road." And then you could already know the equation, put it in and highlight it, and they could have gone, "Ooooh!" And then they would have understood maybe. Maybe they didn't quite understand what they were supposed to do. Maybe they did. But, I'm just thinking it seemed like they paused there for a minute.

Amy: Yeah, I have the same thing, that they didn't understand the directions at all. Because it's like you said. The map is overwhelming when you first look at it with the grids on it, true enough. I think we could have done a little more.

Beth: Well, I did talk to one of my kids at lunch today. And I was like, "What did you think?" And she said one, too many kids were at the board, which I just didn't

intend, and then another that she also said that there were too many lines up there, she was getting confused.

Eric: But, on the two lines, I didn't think the problem was the two lines. I thought the problem was them trying to work with one before they get the other like they wanted. If they'd go on and get one line where they want it before they begin with the other, then it would be ok.

Amy: I also think that it would be really nice to have a second teacher walking around while you were going on, because sometimes I just felt stressed out for [Beth] you know with all of their different questions. I mean I even wrote, "There is WAY too much going on." . . . I know a lot of it was the confusion of the lines, especially when they started showing up white, that caused a lot of chaos, but going from group to group . . . Maybe it's because of the two lines we gave them at first and going up to the board and color lines. There's a lot of things we could have done that could have eased that chaos a bit, but I got a little stressed at one point. I did, for [Beth], because [she was] trying to walk around and deal with it all.

During this debrief session, the group exemplified elements of the exploring TPACK development level for the learning theme by reflecting on the teaching and learning that occurred from the lesson plan they created and implemented. They reflected specifically on evidence of students' learning. They also noted technological and pedagogical issues that contributed to or prohibited students' understanding of the desired mathematics. Amy took notes of suggestions for improving the lesson to be discussed in the lesson revision meeting.

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Carol expressed her desire to implement this lesson with her Transition to Algebra class as an introduction to the relationship of parallel and perpendicular lines. Because the initial research lesson was a review lesson for the Algebra I students, the group quickly suggested that Carol teach the revised lesson to her Transition to Algebra students so that they could see if the lesson truly would allow students to understand relationships of the slopes of parallel and perpendicular lines. Carol expressed concerns about operating the TI-Navigator system from the computer while also facilitating the groups' work. Beth volunteered to perform the needed computer functions for the TI-Navigator system.

Revisions to lesson plan. The group met on the Friday afternoon following the first research lesson to discuss revisions for the lesson. All of the participants were present, but were noticeably physically tired. Some participants brought in their textbooks and lesson plan forms to complete their lesson plans that were to be submitted to the administration for the following week.

The meeting to revise the lesson plan began with confirmation that Carol would teach the second lesson and Beth would control the TI-Navigator system from the computer. From the debrief discussion, the participants decided that each group of students would have a printout of the map with the grid overlay so that they could more easily determine the slopes and y-intercepts of the lines to represent their assigned streets. The participants also decided that the initial phase of the lesson should focus more on graphs and should require the students to find the slopes, y-intercepts, and equations of the lines on the graphs. Carol shared that her classes had recently tested on these concepts.

Because the lesson was initially designed to be used as a review for an Algebra I class, a large portion of this meeting focused on making the lesson appropriate as an introductory lesson for the Transition to Algebra students. Carol made the decision to eliminate the connection to the trucking industry, the part that Beth had added to the previous lesson to meet requirements for her graduate program. Without the trucking connection, there was debate about how to introduce the students to the relationships of the slopes of parallel and perpendicular lines. The dialogue below occurred within the first thirty minutes of the two-hour session.

Gina: You don't really have to do the road map thing, do you, since you don't have to do the trucks?

Carol: No, we could go right into the map.

Gina: That's what I'm saying. You really don't have to do the road map. You could present it a different way.

Carol: Right, we could go into the graph, the street, yeah. What, there's a map before the map, is that it?

Amy: Y'all are saying two different things. No, she's saying you don't have to use the map at all, and you're saying, "Yeah, I can go straight to the map."

Gina: You can use the Navigator and let them find the parallel and perpendicular by graphing or something, if you didn't want to use the road map.

Beth: She's saying you didn't have to.

Carol: Right.

Gina: If you don't - I mean I don't know the capability of your transition students, but I would say that they're gonna have more difficulty than - and that might (pause).

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Carol: They are, that's why we really (interrupted by Eric).

Eric: That was the purpose of the map was to let them see and kinda try to introduce the perpendicular and parallel lines.

Carol: Trying to see it in a practical way on a real-life situation.

Beth: Yeah.

Carol: Maybe what we could do, is to have them, because they need to understand vertical and horizontal, and you know because if our Algebra I [students] don't understand that it poses a problem. So, we talk about vertical and horizontal all of the time, so maybe I could tell them all to graph, you know – how could we do that? Maybe I could say, "Boys, graph a vertical line, and girls, graph a horizontal lines" or something. And we could have them figure out that those are parallel lines. And, then do the map and let them do that after they just practice it on a regular screen maybe, to show the real-life application, or do we want to do the real-life first?

Amy: I think real-life first.

Carol: Real-life first?

Amy: Yeah, because, I mean you've already gone over how to find slope, how to graph the equation. Well, that's basically what it is. I mean some of the groups - my group got it that first time with going up four and over seven, or whatever it was.

Carol: Right, you know because we didn't want the undefined and zero slope either, did we?

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Amy: But, I think they should be able to do that. Now, it's gonna, we're gonna have the laminated sheets at their desks now, so they can do that on their own, and write on it as much as they want so they don't have to go up to the board. It won't be that mass confusion anymore, and then they should be able to pick two points that are on the road from their laminated sheet and be able to graph it. I mean, if they already know rise over run and y-intercept (interrupted by Carol).

Carol: Yeah, that's gonna help them a lot to know that.

Amy: The only thing I would emphasize in the warm-up is that y-intercept isn't always zero or 1, or I mean (pause).

Carol: Right. Well, we did some today where it was halfway between.

Amy: That's the only thing I would really, with your class, worry about.

Carol: Right.

Amy: I mean all of the other, that's the natural worry of the lesson, right?

Carol: Ok, so we're gonna keep the way they come in the room?

Gina: Well, I just said that because I thought they were having trouble getting the lines to match those roads. And, I'm thinking transitions is below that, so (pause).

Facilitator: Do you think it will help though to have it at their desks where they can look at it and draw on it?

Gina: I mean it took them what? Twenty minutes? It's gonna take transition (interrupted by Carol).

Carol: Three and a half days (laugh).

Amy: Well, we also said that we're not going to give them two lines at a time. That we're just gonna give them one line, and if they get that one line, then we give them the next line to keep them kinda busy while the other students get theirs. And, I think also, if they only get that one line, throughout the class, well then we talk about parallel lines. If they get both lines, then we mention perpendicular. Like we do what they do. They should be able to get one line, right?

Beth: Or you get intersection.

Carol: They should.

Amy: I mean I think that was part of problem with the lesson then. We gave them too much. There were too many options. They weren't all focused on the same line.

Tension filled the room with several moments of awkward silence. The group members, with the exception of Gina, were determined to retain the map exploration in the lesson. With this exploration as an inductive introduction to the relationships of the slopes of parallel and perpendicular lines, the lesson plan exemplified the exploring level for the teaching theme of the TPACK development model. The participants demonstrated the elements of exploring level of TPACK development for the learning theme in reflecting on the first research lesson and revising the plan with a concern for guiding students' understanding and to use the technology as a tool to facilitate the students' learning. Gina's concern about the students' potential difficulty demonstrated that she was considering students' prior knowledge and understandings. The defensive group members did not allow Gina a chance to offer any other suggestions for the lesson. Thus, Gina's level of TPACK development in suggesting removal of the map exploration

was unclear at this time in the meeting. Gina's comments were scarce throughout the next hour of the session.

After some discussion about which streets to assign to the transition students and how to make the task more accessible, Eric offered a suggestion to supply several slopes from which the students could select. The dialogue below documents Eric's suggestion.

Eric: Can we give them maybe 9 or 10 slopes and say, "One of these is the slope." Maybe, "You count your rise and your run, whichever one is" (interrupted by Beth).

Beth: Like give them an option?

Eric: Right, give them some options, whichever one is closest. Try the one closest to that number.

Amy: I'd hate to start off with that, because we don't want to sell them short.

Beth: Yeah, I think maybe after a certain amount of time.

Amy: But, like if after a certain amount of time we could go by, "Here are some options. Try these."

Eric: No, but if you're putting the different slopes on the board, if you've got 9 or 10, they go up there and count then, they can kinda figure out from that which one is closest to it.

Beth: But, I can see my kids typing in every one of them.

Amy: Yeah, that's what I was afraid of.

Carol: That's what mine would do, yeah.

Beth: Yeah.

Amy: They would type it in and just let it go up there. "Oh, well that's not it."

Later in the meeting, following discussion about whether the focus of the lesson was writing equations and translating lines or on the relationships of the slopes of parallel and perpendicular lines, Eric added the following, "If we're trying to get them to see the relationship between parallel and perpendicular, it's not gonna help to put those, put a pool of numbers up there for them to choose from." Eric indicated by this statement that supplying a collection of slopes would not affect the students' realization of the relationship of the slopes of the parallel and perpendicular lines. He viewed this collection of slopes as a way to assist students in their struggle of writing the equations of the lines to allow time for examination and discussion of the relationships of the slopes. The collection of possible slopes would also encourage the use of teacher-intended slopes rather than slopes that did not accurately represent the slopes of parallel and perpendicular lines.

A few moments later, Amy replied:

I like the pool of numbers idea. I just don't want to give it to them right off the bat. I want to see them try to find it themselves, and see how close - and the ones I see the major struggle in their eye, be like, "Ok, let's try these."

The group made the decision to include the collection of possible slopes only after the students had the opportunity to explore in writing the equations independently. The addition of this collection of possible slopes indicated elements of the adapting level for the teaching theme. With these slope choices, the students would be allowed to explore for only a portion of the lesson with more teacher direction. The participants still exhibited elements of the exploring level of TPACK development for the learning theme in their reflecting on the prior lesson and

revising the plan with a "concern for guiding students in understanding" (Niess et al., 2009, p. 21) the mathematics.

Later in the lesson, concern again arose about students composing equations that did not accurately represent parallel and/or perpendicular lines. Gina commented again regarding her concerns with using the map exploration.

Gina: What about, what about? I just don't like the map.

Dana: Because the lines, the roads are (inaudible)?

Gina: I just don't think transition is gonna - What about if you did a (stopped talking as she was looking at an activity described in textbook)

Carol: I think I saw that today.

Gina: Put the points up there on the Navigator. Just have some points graphed. And it says here to have the students to try to come up with their own equation that would pass through as many points as they can. All right, then their lines will be graphed, and then you can start comparing their equations. "Ok, kids, what do you notice about the equations of (motions with hands) certain lines." "Oh, the slopes are the same."

Dana: And have the points such that they make parallel lines.

After a few moments, the discussion continued.

Gina: I mean you still use the Navigator. You're still gonna use the technology.

Amy: But, if you want to give them points, put the points up there!

Dana: Yeah, yeah.

Amy: Put the big dots on the streets.

Beth: Yeah, we could.

Carol: Ooooh!

Amy: I mean we can't change the map though, that's our whole lesson.

A few moments later the dialogue shifted to a discussion of how to utilize given points on a graph to provide the opportunity for students to discover the relationship of the slopes of parallel and perpendicular lines.

Dana: And would you finagle them so that you do get a lot of parallel lines though? I mean is that the idea? So that when they write their equations, they come up with (interrupted by Beth).

Beth: Well, you're gonna have a lot of points up there. How do you know they're gonna pick the two?

Dana: Mmm-hmm. Yeah, again, how do you guarantee the parallels? Which was nice about the streets, you know?

Carol: Yeah, because if they do it on this, they're gonna do the zero and undefined and that wasn't what we wanted them - unless we can arrange it to where it won't - unless we tell them they can't have (interrupted by Gina).

Gina: I mean they don't have to all be parallel or all be . . . I mean you can have some just intersecting lines and then let them discover the ones with the same slopes are all going the same direction.

Dana: But, do you think you will, for sure, get parallel equations?

Carol: You could (pause as she walks to the screen).

Dana: That's what I'm saying. Is there a way you could do the dots so that you guarantee it sort of?

Carol: (At the screen pointing to indicate collinear points) Like you could do a dot here, here, you know and then kinda make it to where (interrupted by Dana)

Dana: I know . . . yeah, that's what I'm saying . . . somehow make it (interrupted by Beth)

Beth: What if you have? Unless you assign them two dots, you might not do that. You might not get that.

Dana: Well, she was saying if you could make it where you get the most dots on your line, right? So, if you could line a whole bunch of them up in such a way that, "Oh, yeah, look at all these lines, they're right - you know all of these points are right in a line." And then that way they'd go for them quickly. And then have some here, some here, you know where they're obviously in a line without actually being a line.

Gina: That's up to you, [Carol]. You're teaching it. I'm just trying to think on transition level. And that -1.9 and all that, that's just not gonna (long pause with awkward silence).

A few minutes later, Carol offered a suggestion that helped the group reach a compromise concerning the lesson.

I think that they would think that it would be really cool, if somehow we could maybe do that as - this is gonna change the whole thing though - but if [writing the equation of a

line to pass through as many of the given points as possible] was like the warm-up and then put the map on there, they would be like, "Whoa!"

From this suggestion, the group decided to start the lesson with Gina's idea of writing an equation of a line to pass through as many of the given points as possible. The points, however, were purposefully selected to match points that corresponded to streets on the map. As the groups submitted their initial equations, Beth would manipulate the lines displayed by the TI-Navigator system to thicken the lines and to assign line colors to the groups. This initial color assignment was intended to reduce confusion later in the lesson. Following this task, Beth would import the map as the background image as the teacher distributed paper copies of the maps with the grid and point overlays. The teacher would assign each group a street for which they were to submit an equation. If time permitted, each group would submit an equation for a second assigned street. With the purposefully selected points as a guide, the participants anticipated that the students would be more likely to submit equations that would represent the desired parallel and perpendicular lines.

The considerations for this revised lesson plan included pedagogical supports to facilitate technological explorations that would allow a better understanding of the mathematics. Both the group debate about how best to support students' thinking and understanding through the technology use and the compromise that was ultimately reached demonstrated elements of the advancing level of TPACK development for the learning theme. In their reflection and planning, the participants displayed "concern and personal conviction" (Niess et al., 2009, p. 22) to increase student thinking. The final lesson design included integral use of the technology to develop the students' mathematical learning. The TPACK level for the teaching theme for the

final lesson plan was exploring. The classroom-tested lesson was redesigned to utilize the technology as a learning tool to engage the students in higher-level thinking through exploration. The teacher's role would be that of guide, not director, of the exploration.

Second Research Lesson Debrief. The participants met the afternoon of the second lesson for a debrief session. Because only Amy, Beth, and Carol were present for the second lesson, the group viewed the video of the lesson before beginning discussion. I asked the participants to take observation notes as they viewed the video. The comments below represent some of the participants' reflections on the second research lesson as well as suggested revisions to the lesson plan. As the teacher of the lesson, Carol was the first group member to reflect on the lesson.

> The student who [was also a student in the class for the first research lesson] came up to me afterwards and she said . . . having the maps with the dots on it really did help. She said that she really liked that part of [the lesson] because it made it so much easier than having to look up [at the screen] and everything. So, I think the revisions we made [to the lesson plan] helped to help them understand [the mathematics].

When asked if she had anything else to add before other group members started commenting, Carol reflected on the time restraints.

> I needed another day though to get it all done, because everything was so new to them and everything. They just didn't have time, but I didn't want to cut them off, you know, while they were still trying. And they never got to a point where they looked like they were bored and not doing anything . . .

Beth was the second group member to comment. Regarding the technology operation, she stated, "I will say I liked how we went ahead and had [the students submit equations of lines in the beginning of the lesson], so I could go ahead and change the color and thickness real quick." Beth also noted that smaller group sizes might be a consideration for future revisions. She shared how that in some groups, one student dominated the printed map. She suggested that either all students should receive a printed map or the group sizes should be reduced to engage all students in the task.

With Beth operating the computer system and Carol teaching the lesson, Amy was the only participant recording observation notes during the second research lesson. Amy's initial comments regarding the lesson are below.

Well, I thought again, the whole idea with the maps being at the table, that was great. Because already we were talking about it, they were like, "No, I don't want to do that." But, then we handed them the map and they kinda felt comfortable with that like, "Well ok, here we go. We can see this." . . . I thought the number bank that we talked about, actually I didn't think we needed it in the lesson.

Dana asked if any of the students used the slopes recorded as options on the board. Amy replied:

I would say yes, but when [Carol] put [the slopes on the board] . . . a lot of [the groups] already had one line. They already had something [displayed on the screen], so [the slope bank] was kind of a manipulation of [their equations], so it didn't hurt.

Carol noted that she did not add the collection of slopes to the board until the last five minutes of class, because she forgot. Carol stated, "I don't think it really helped anybody." She

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added, "If I had put it up there before they started, all they would have done was go down the list. It was in the plan, and I didn't know if I had to stick to it," she explained.

Dana commented that starting the lesson by asking students to write equations of lines to go through points on the graph before the map image was imported allowed scaffolding to the map exploration. Dana stated,

What [the students] did, coming in and then graphing the points without the road map, and then the road map itself, I mean I think it started with little baby steps really nice. (Amy agreed.) So that by the time it got to the maps, they pretty much knew the slope, knew how to write the equation, and it wasn't as overwhelming as it would have been just to start off with that map right away.

Amy added that the focus of the lesson unintentionally changed in transitioning from the initial phase of the lesson to the map exploration. The following dialogue occurred regarding the focus of the lesson.

Amy: We started with the points like [Dana] said, it flowed well to get to the map, but then when we got to the map, [and] we changed from just graphing the points, to hitting the streets exactly. And, I don't know if that's what we intended to do especially with the build up of - we were talking about the points, the points, the points, and then all of a sudden it's like, "Well this line doesn't hit the street." Were we going for the street, or were we going for the points? And that's part of, I don't know, I guess we just didn't talk about it, 'cause I did the points, and some of them (interrupted by Dana).

Dana: Were the points not on the streets?

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Amy: No, the points were on the streets. It's just the line[s] didn't match the streets exactly. Like the street would be going like this and your line (motioned with arms and hands). [The line] hit [the street], but it was a little off.

Dana: But, it would be on the points.

Amy: Yes, it would be on the points, not necessarily on the street.

Dana: Right.

Amy: And, I liked it if we took it from the points to say, "All right, that's our points. [Using the points] got you close, but let's try to get closer to the street." I like that, but we didn't intend for that to happen.

Amy offered another consideration for future revisions to the lesson plan.

Which we could have, if we [had] thought about perpendicular and parallel, you know, not really coming together like that, we could have not given all of the students a line that was supposed to be parallel. You know, given some the streets that looked like this (motioned with arms) and then the other[s] the perpendicular, since we had so many groups . . . That way everybody's at least working on different things. So we could have done that, but we chose to do all parallel first and then do perpendicular.

After a few moments, the dialogue regarding successful revisions to the lesson plan as well as suggestions for future plans continued.

Gina: I'm glad we put some points on there, because they did make it easier for [the students] to understand what they were supposed to do. I mean, if they just saw the map right at the beginning, they wouldn't have got anything out of it.

Dana: And then having the individual maps with the groups, that was a real good idea.

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Carol: I don't think if we had given [the students] the maps without those points they

would have been able. . .

Dana: That might be the next thing you would do, you know. First the points without the

map, then the map with the points, then the map without the points. You know,

it'd be the next step.

Eric noted that extending the initial phase of the lesson to include writing the equations of

lines instead of only determining slope, made a difference in the students' success with the map

exploration. With regard to the collection of optional slopes written on the board at the end of

class, he added,

I thought [when the optional slopes were written on the board] would have been a good

time to point out that if [the students] change [the fractional slopes] to decimals they

would know which [slope] was closer to their fraction, because I don't think at that point

a lot of those students knew how to compare….I thought that was an opportunity to put

[comparing fractions] in [the lesson].

During the debrief session, participants noted pedagogical and technological decisions

that were made in the lesson plan revisions that were successful in promoting students'

understanding of the mathematics content. In implementing and reflecting on the second research

lesson, the participants exemplified elements of the exploring level of TPACK development for

the learning theme. The participants focused on how the lesson plan revisions supported

students' learning of the mathematics through the teacher-facilitated technology exploration.

Summary. Lesson study is designed to engage inservice teachers in collaboratively

planning, implementing, reflecting on, revising, implementing, reflecting on, and revising a

detailed lesson with the goal of improving students' understanding. This technology-based lesson

study also compelled the participants to consider how to incorporate the technology in the lesson

to promote students' understanding of the mathematics. As the lesson study progressed, the

TPACK development levels for the whole-group interactions also progressed. The whole-group

interactions during their participation in the lesson study aligned with the adapting and exploring

levels of TPACK development for the curriculum and assessment and teaching themes. For the

learning theme, whole-group interactions demonstrated elements of adapting, exploring, and

advancing TPACK levels. Figure 3 summarizes the TPACK development levels that were

evidenced in the different meetings of the lesson study.
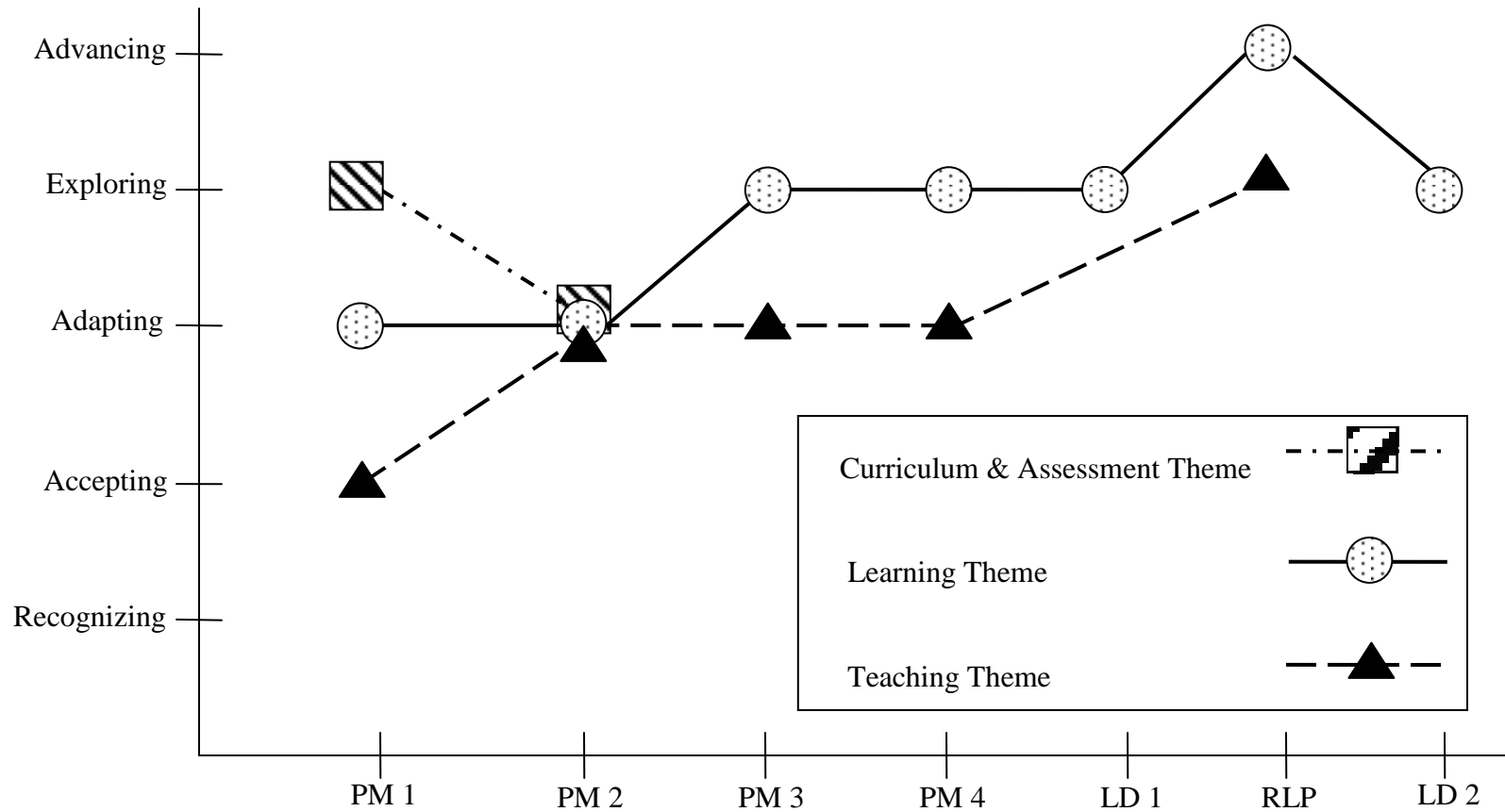
Figure 3. Summary of levels of TPACK development exemplified during lesson study group meetings. PM 1 = First Planning

Meeting, PM 2 = Second Planning Meeting, PM 3 = Third Planning Meeting, PM 4 = Fourth Planning Meeting, LD 1 = First

Lesson Debrief, RLP = Revising Lesson Plan, LD 2 = Second Lesson Debrief.

Participation in whole-group interactions with these higher levels of TPACK did not

indicate, however, that each individual had reached those levels of TPACK development with

regard to the TI-84 graphing calculators and the TI-Navigator system. Individual cases of the

four participants who had the TI-Navigator technology will be discussed in the following section.

Individual TPACK Development

During the whole-group interactions, the design of the technology-based lesson study

promoted actions that aligned primarily with the adapting and exploring levels of the curriculum

and assessment, learning, and teaching themes of the TPACK Development Model (Niess et al.,

2009). The individual participants, however, varied in their personal TPACK development.

Cases of the four participants who had a TI-Navigator system in their classrooms are discussed

in the sections that follow. Pre- and post-TPACK development levels will be discussed with

evidence from the TPACK Development Model Self-Report Survey, initial interview, initial

classroom observation, post-interview, and classroom post-observation.

Beth. Beth was in her fourth year of teaching. Beth earned a bachelor's degree in

secondary mathematics education in 2007. During the study, she was completing her final

semester in a master's program in curriculum and instruction with emphasis in secondary

mathematics education. In her classroom, she had a classroom set of TI-84 plus graphing

calculators, the TI-Navigator system, and an interactive white board. On the Survey of

Technology and Educational Background, Beth reported having utilized graphing calculators

both in her high school and college educational experiences. During the initial interview, Beth

clarified that her calculator use in high school and college was primarily computational.

TPACK Development Model Self-Report Survey. On the TPACK Development Model

Self-Report Survey, Beth ranked herself primarily as accepting and adapting, with the exception

of one exploring/advancing. The data from Beth's TPACK Developmental Model Self-Report

Survey are detailed in Figure 4. The theme and descriptor of the model are listed in the left

column with the other columns representing the five TPACK development levels. The specific

TPACK development level self-reported is indicated with a check mark. Clarification is given in

parentheses as needed.

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TPACK Self-Report Beth	Recognizing	Accepting	Adapting	Exploring	Advancing
Curriculum & Assessment Theme – Curriculum Descriptor				✓ (for TI-Navigator)	✓ (for graphing calculators)
Curriculum & Assessment Theme – Assessment Descriptor			✓		
Learning Theme – Mathematics Learning Descriptor		✓			
Learning Theme – Conception of Student Thinking Descriptor			✓ (indicated trouble finding time)		
Teaching Theme – Mathematics Learning Descriptor			✓ (indicated a desire to do more, but struggles with time)		
Teaching Theme – Instructional Descriptor			✓		
Teaching Theme – Environment Descriptor		✓			
Teaching Theme – Professional Development Descriptor	(No level marked Comment: "Already went to workshop")				
Access Theme – Usage Descriptor			✓		
Access Theme – Barrier Descriptor		✓			
Access Theme – Availability Descriptor			✓		

Figure 4. Data from Beth's TPACK Development Model Self-Report Survey.

Initial interview. The initial interview revealed evidence of Beth's initial TPACK levels for the various themes of the TPACK Development Model. Descriptions in her initial interview of her technology use indicated that her initial TPACK levels matched her responses on the TPACK Development Model Self-Report Survey for the descriptors discussed. When I asked how she felt about teaching with technology, Beth replied with general comments about her technology use.

I mean I like using technology. One, seems like I get more accomplished in the lesson, because it helps, it helps them to see the concepts better, especially with the TI-Navigator. I just feel like I can skip all the little steps, the process getting there, and just go ahead so that they can understand the end result, the concept of the whole thing.

In an effort to obtain more detail about her technology use, I asked for a specific example of how she had used the technology to help her students "see the concepts." However, Beth was not able to provide a specific example. Using the technology to reinforce concepts would indicate the adapting level of TPACK development for the teaching theme, mathematics learning descriptor. Without an example of this conceptual understanding through technology use, however, this level was not assigned.

I asked Beth to describe her experiences as a teacher using instructional technologies. Beth addressed how using the technology simplified some classroom tasks.

Since I've been using the technology I can, I can see how it's easier to show the stuff. Especially with, I mean just graphing in general, it's easier so you can show everybody what it looks like instead of - one, it saves me, as far as the teacher, it saves me time than having to go around and look at every calculator and make sure [the students are] where

they're supposed to be. So, it kinda helps, I guess somewhat classroom management, it

helps.

This statement supported Beth's report of the accepting level of TPACK development for

the teaching theme, environment descriptor. The environment Beth described during technology

incorporation was structured and teacher-directed. The technology was utilized to help control

the classroom environment as the teacher "show[ed]" the mathematics to the students.

I asked Beth about factors that influenced her decisions to use or not use available

instructional technologies. Beth discussed concerns about time management.

Well, like to use it is the motivation for sure and just the visual aid. The thing that I don't

use it for is just the time it takes to set it up and then get it started, because the kids forget

their password or forget their username and I have to go look it up, or (pause) it's just a

lot (pause) it's very time-consuming and a lot of times I don't have that time.

Beth's choice not to use the technology on a regular basis because of her concern about

student access and management issues provided evidence of the accepting level of TPACK

development for the access theme, barrier descriptor. The implication that students forgetting

passwords takes away from instructional time supported the accepting level of TPACK

development for the learning theme, mathematics learning descriptor, but also implied the

recognizing level of TPACK development for the teaching theme, mathematics learning

descriptor.

When I asked how her students use instructional technologies to learn mathematics, Beth

again described how she directs the students in using the technology.

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Well, I started off toward the beginning of the year using the TI-Navigator. And, I've
kinda not had time to set it up for a while. When I first was using it, I used it a lot just me
doing it to show them like on the SMART board what the screen looks like so they can
see what theirs should look like, kinda just trying to guide them through it. But other than
that, we've looked at how to graph. Just showing the different representations has been
nice. Just seeing the graph, the table, and everything, so that's really helped.

This quote verified Beth's accepting level of TPACK development in the access theme,
barrier description. Her concern about time issues related to access and management of the
technology presented a barrier to her technology use. When she did implement the technology,
she described a controlled classroom where she guided the students in their technology use,
providing evidence of the accepting level of TPACK development in the teaching theme,
environment descriptor. The last two sentences of the quote referred to utilizing the technology
to examine different representations. This supported Beth's adapting level of TPACK
development for the access theme, availability descriptor. Students would not be able to quickly
examine these different representations if they had to create the graphs and tables by hand.

I questioned Beth about her lesson planning and the role that technology plays in making
those plans. Additionally, when I asked how the progress of one lesson affects the next day's
lesson, Beth described her typical lesson.

Well, pretty much almost every day I use a PowerPoint for the most part. So, that kinda, I
mean I would go step-by-step, these are the examples I'm going to go over for my
PowerPoint. But, when I was using Navigator, kinda wherever I ended would kinda have
to be where I picked up the next day with it. So, that's kinda how it affected the next day.

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A lot of times we would - the kids would kinda go in depth about different things and then I would maybe the next day change my lesson plan to go a different direction.

Initial classroom observation. I witnessed Beth's typical daily lesson described during the initial classroom observation with a class of Algebra I students. As students entered the room, they got their assigned calculators and began working on five "warm-up" equations and systems of equations that were displayed on the interactive whiteboard. Students volunteered to display their solutions on the board. Beth explained the steps in solving these equations, making corrections to student work as needed. One student described how she checked her solution to a system of equations using the graphing calculator.

Beth displayed notes and examples using the PowerPoint presentation provided by the textbook company, briefly explaining the notes and guiding students through the examples step-by-step. For one example, Beth directed the students to type the first given equation into their calculators as Y1 and the second given equation as Y2. When the students viewed the graph on their calculators, they recognized the lines as parallel. Viewing the graph reinforced the concept given in the notes that systems of parallel lines would have no solution. The teacher continued discussing more notes, examples, and definitions from the textbook PowerPoint presentation.

Students had access to the technology from the moment they entered the door of the classroom. Although the students used the technology freely to check computations, the students used the technology for instructional purposes only briefly during the lesson. This brief use was in a structured, controlled, teacher-directed environment. This classroom observation provided evidence for the accepting level of TPACK development for the teaching theme, environment descriptor, and for the access theme, usage descriptor. Although Beth indicated the adapting

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level of TPACK development for several descriptors on the TPACK Development Model Self-Report Survey and during the initial interview, support of the adapting level of TPACK development for these descriptors was not evident during this initial classroom observation.

During lesson study. Beth took an active lead role in planning, implementing, reflecting on, revising, re-teaching, and reflecting on the research lessons during the lesson study. She operated the technology for all of the group meetings, taught the first research lesson, and operated the technology for the second research lesson.

Post-interview. Although Beth took a lead role throughout the lesson study in modifying the lesson ideas to integrate the technology use to promote students' understanding, in operating the technology during the group meetings and in the second research lesson, and in teaching the first research lesson, her comments during her post interview were similar to those in the initial interview.

One area that was different from before the lesson study was the teaching theme, professional development descriptor. On the TPACK Development Model Self-Report Survey, Beth did not respond to the statements for this section. Rather, she commented that she had already attended a workshop, indicating that she felt that she did not need more professional development. During the initial interview when I asked how other teachers would describe her use of instructional technologies and why, Beth indicated that most of the other teachers knew that she was good with technology and would come ask her for help if they were having trouble with their own technology. Beth's answer in the initial interview addressed technological difficulties, not instructional strategies for utilizing the technology. During the post-interview, Beth responded to the same question as follows.

I think they would say that I - I mean I use technology in my classroom a great deal. I

think mainly 'cause they ask me how to use [the technology] quite a bit, but I think that

most of us, especially with the TI-Navigator, we're kinda using it a little more and more

each time, so we're kinda just talking to each other and getting ideas from each other.

Beth's indication of continued collaboration and exploration of ideas for the use of the TI-

Navigator system provided evidence for the adapting level of TPACK development for the

teaching theme, professional development descriptor.

When I asked Beth about changes that she would like to occur in her implementation of

instructional technologies, Beth discussed her desire to implement the technology as a learning

tool:

I think just more like - like even like a discovery-based type - kinda like what we did with

our lesson, things like that. I mean one having the technology, but also getting the

students to talk about the mathematics through the technology [use] and things like that.

Beth's expressed desire to implement the technology for discovery learning and to promote

mathematical communication indicated that she "understands some benefits for incorporating"

(Niess et al., 2009, p. 20) the technology as a learning tool. This understanding implied the

adapting level of TPACK development for the curriculum and assessment theme, curriculum

descriptor. Although Beth reported the exploring level of TPACK development for this

descriptor on the TPACK Development Model Self-Report Survey, there was no evidence in the

initial interview or in the classroom observation to support her initial TPACK level for that

descriptor.

During the lesson study, in taking a lead role in planning the lesson, Beth began to investigate using the technology as a tool for learning and teaching. This beginning practice coupled with her expressed desire to continue using technology for discovery learning displayed evidence of the adapting level of TPACK development for the learning theme, mathematics learning descriptor, and the teaching theme, environment descriptor. Both of these descriptors were at the accepting level before the lesson study.

Classroom post-observation. For the post-observation, I observed Beth's instruction with a class of Algebra I students. When I arrived for the classroom post-observation, Beth remarked that she forgot I was coming that particular day for the post-observation. I had previously commented to the participants that I was interested in seeing how they use the technology in their classes on a regular basis. I did not want them to plan a "show" for the observation. I asked Beth if she would rather me come another day, but she decided to proceed with the post-observation.

As students entered the room, they took their assigned calculators and began working the "warm-up" problems displayed on the board. One student was called to the board to work one of the "warm-up" problems. Beth worked the other four "warm-up" problems, asking students for input as she worked. Beth again used the PowerPoint presentation from the textbook company to present the day's lesson. The lesson focused on finding the zeros of a quadratic function. Beth reminded students how to solve a quadratic algebraically by factoring. The PowerPoint presentation demonstrated how to check the zeros by substituting them into the equation and displayed quadratics with two zeros, one zero, and no zero. The presentation also supplied notes about how to use the zeros to find the axis of symmetry. Additionally, the presentation provided a formula for students to use to find the x-coordinate of the vertex of a quadratic function.

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Throughout the lesson, the students used their graphing calculators only for the purpose of computations. Beth directed the students to, "Type this in your calculator," when substituting in the *x*-coordinate of the vertex to find the *y*-value.

Beth presented two application problems toward the end of class. For the first problem, she drew a picture diagram on the board to model the problem situation. She asked single-answer questions as she demonstrated how to set up and solve the problem. She directed the students to "type it in" their calculators to find the solution. For the second problem, the students worked the problem themselves before the steps to solve and the answers were displayed on the PowerPoint presentation. Beth walked around the classroom observing the students' work. She remarked that those who did not get the correct answer probably did not "type it in correctly." She reminded the students of proper use of parentheses in entering the expression in the calculator.

Although Beth indicated in her interview a desire to integrate the technology as a learning tool, evidence from the classroom post-observation did not indicate the technology being used in that way. The teacher-directed use of the calculators for rote computations indicated the recognizing level of TPACK development for the teaching theme, instructional descriptor. The students' use of calculators for computations in the real-life applications implied the recognizing level of TPACK for the access theme, availability descriptor.

Summary. "Two heads are better than one. . .And I think working with other people and other teachers, you gain a lot more. I mean your lesson improves immensely versus you just doing it." This was part of Beth's response during her post-interview when I asked her to describe her experiences during the lesson study. Beth displayed much higher TPACK levels

when working together with the group during the lesson study and reportedly working with other teachers after the lesson study.

Beth's self-reported data indicated the adapting level of TPACK development for the majority of the descriptors. The initial classroom observation provided evidence for the accepting levels of TPACK development for the teaching and access themes. In working with the group, Beth began exploring using the technology as a learning tool, displaying adapting levels of TPACK development for the learning and teaching themes. Following the lesson study, Beth indicated that she and other teachers were sharing ideas for using the TI-Navigator system, implying the adapting level of TPACK development for the curriculum and assessment theme. During the post-classroom observation, however, Beth displayed only the recognizing level of TPACK development for the teaching and access themes. Figure 5 summarizes the TPACK development levels that were documented in Beth's case from initial and post-interviews and from initial and post-classroom observations.

TPACK Summary Beth	Self-Report	Initial Interview	Initial Observation	Post-Interview	Post-Observation
Curriculum & Assessment Theme – Curriculum Descriptor	4 (TI-N) 5 (GC)			3	
Curriculum & Assessment Theme – Assessment Descriptor	3				
Learning Theme – Mathematics Learning Descriptor	2	2		3	
Learning Theme – Conception of Student Thinking Descriptor	3				
Teaching Theme – Mathematics Learning Descriptor	3	1			
Teaching Theme – Instructional Descriptor	3				1
Teaching Theme – Environment Descriptor	2	2	2	3	
Teaching Theme – Professional Development Descriptor				3	
Access Theme – Usage Descriptor	3		2		
Access Theme – Barrier Descriptor	2	2			
Access Theme – Availability Descriptor	3	3			1

Figure 5. Summary of Beth's TPACK development levels. 1 = Recognizing, 2 = Accepting, 3 = Adapting, 4 = Exploring, 5 = Advancing, TI-N = TI-Navigator system, GC = Graphing Calculators.

Carol. Carol was in her eighteenth year of teaching. Six years of her teaching experience was teaching computer classes. Her highest college degree was a bachelor's degree in elementary education, earned in 1993. Carol reported having used calculators in her educational experiences to check work. She also reported learning about computer programming as a student. Carol had a classroom set of TI-84 plus graphing calculators, a TI-Navigator system, and an interactive whiteboard in her classroom. At the beginning of the study, Carol reported that she had not yet used the TI-Navigator system with her classes.

TPACK Development Model Self-Report Survey. On the TPACK Development Model Self-Report Survey, Carol ranked herself in the exploring level for several descriptors. For three descriptors, Carol indicated agreement with the statements from multiple levels. One descriptor had no mark indicated. The data from Carol's TPACK Developmental Model Self-Report Survey is detailed in Figure 6. The theme and descriptor of the model are listed in the left column with the other columns representing the five TPACK development levels. The specific TPACK development level self-reported is indicated with a check mark. Clarification is given in parentheses as needed.

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TPACK Self-Report Carol	Recognizing	Accepting	Adapting	Exploring	Advancing
Curriculum & Assessment Theme – Curriculum Descriptor				✓	
Curriculum & Assessment Theme – Assessment Descriptor				✓	✓
Learning Theme – Mathematics Learning Descriptor			✓		
Learning Theme – Conception of Student Thinking Descriptor	No level marked				
Teaching Theme – Mathematics Learning Descriptor	✓ (Desire to change)				
Teaching Theme – Instructional Descriptor		✓	✓		✓
Teaching Theme – Environment Descriptor				✓	
Teaching Theme – Professional Development Descriptor		✓			
Access Theme – Usage Descriptor				✓ (calculators not TI-Navigator)	
Access Theme – Barrier Descriptor	✓		✓	✓	
Access Theme – Availability Descriptor		✓			

Figure 6. Data from Carol's TPACK Development Model Self-Report Survey.

Initial Interview. Carol's descriptions of her technology use from her initial interview did not align with the higher levels of TPACK development that she indicated in her TPACK Development Model Self-Report Survey. When I asked her how her students use instructional technologies to learn mathematics, Carol described their practices.

> [The students] learn all the concepts through taking notes and through watching the PowerPoints. And, then we practice. If we're graphing lines, we practice the graphing lines through watching, you know, the PowerPoints, and I instruct them how to do it on paper. But, then they practice using the calculators also and checking their work, so they use the graphing calculators to reinforce the skill that they've already learned and to check their work, you know, and to explore new things with [the calculators]. You know, sometimes I teach them the technology first, to show them, you know, this is where we are going to be graphing lines, and this is what they look like. And, here's one way you can do it. Now turn [the calculators] off, and let's, you know, do it by hand. And so [the calculators are] just an integral tool that, you know, we use in every class period.

The descriptions that Carol provided of how her students use technology aligned with the lower TPACK development levels for the learning and teaching themes. Her students using the graphing calculators to practice and reinforce skills they have already learned how to do with paper-and-pencil methods indicated the recognizing level of TPACK development for the teaching theme, instructional and environment descriptors. The fact that she sometimes introduced technology methods before demonstrating paper-and-pencil methods exemplified the accepting level of TPACK development for the learning theme, mathematics learning and conception of student thinking descriptors.

When I asked about the factors that influence her decisions to use or not use available instructional technologies, Carol referred to a particular group of students.

I'm teaching a group of seniors who have never had high-school math before. They're 12th-grade, certificate seniors, and there's no way I can go right now and teach them all the skills they need. But, because they have that tool (graphing calculator) in their hand, they're performing well. I had four on the first diagnostic test we gave them that show at a proficient [level] on the state test because they have that tool to help them. So, it's opening up a world to them that they would have never had if they couldn't use that [graphing calculator].

When I asked Carol for more details about how these senior students are using the graphing calculator, Carol replied:

The Y= . (little laugh) You know, I've shown them how Y= is so important because you can see that picture, you can pull up your table of values, you can determine parallel and perpendicular lines through that, you know. With the algebra concepts, there's SO, SO much you can do with those, you know, with those calculators. We have the programs off right now. We're gonna introduce those later, but even just having the calculator, they're finding slope where they probably would have gotten confused if they were trying to do it by hand, you know. . . [The graphing calculator] just helps them because they're so low on their integers and any application of integers, and so because they have those [graphing calculators], they're able to perform where they wouldn't be able to without them. It would be too hard.

With regard to this particular group of students, Beth's descriptions of graphing calculator use to provide access to mathematical concepts that would otherwise be "out of reach" (Niess et al., 2009, p. 24) implied the adapting level of TPACK development for the access theme, barrier and availability descriptors. For the usage descriptor of the access theme, however, the use of the technology to "in every aspect of the mathematics class" (Niess et al, 2009, p. 24) exemplified the advancing level of TPACK development.

When I asked about her concerns regarding using instructional technologies in the classroom, Carol expressed her concern about time required to learn how to use the system.

> The only concern that I have is I want to get my TI-Navigator system going. And, I'm just afraid of that first couple of days getting it set up and getting those kids on there, and I need to just get over that. And, I plan now that when we come in Thanksgiving, after Thanksgiving, it's gonna be up and going. . . . I know how useful it'll be for them to use [the TI-Navigator system], so I'm going to put that fear away, and not worry about that it's going to take maybe a whole class period, you know, to get going. . . . I know, once I start using [the TI-Navigator system], that it's really going to increase the kinds of questions that I can ask the kids and the kinds of lessons that I can plan. And, it can totally change my whole planning based on that. And, if it'll help the kids, I've got to do it and get over that fear.

In her closing remarks, Carol added:

> I'm just glad that this opportunity presented itself, because I probably would have waited a little bit longer to use that [TI-Navigator] system, and now that I know that we're doing this [study], it, it's kinda motivating me to get a fire going and start [the TI-Navigator

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system] up, and I'm excited about it! I think that it's going to work out really well, so it's

kinda like, this is fate coming on, and it's just given me a push in the right direction.

Carol expressed concern that the need to teach the students about the TI-Navigator system would

take away mathematics instructional time. These statements implied the recognizing level of

TPACK development for the teaching theme, mathematics learning descriptor. On the TPACK

Development Model Self-Report Survey, Carol indicated agreement with the statement from the

recognizing level for this same descriptor. Beside the statement she wrote, "I have felt this way,

but want to change."

Initial classroom observation. I initially observed Carol's instruction with a class of

Algebra I students. As the students entered the classroom, they got their assigned calculators and

began working the review that was displayed on the interactive whiteboard of solving systems of

equations in two variables by graphing and by substitution. Carol informed her students that they

would use their calculators to look at the first example to be solved by graphing. The students

recognized that in order to view the graph of the system of equations, they would need to have

the two equations in slope-intercept form. Carol demonstrated how to transform the equations

from standard form to slope-intercept form, asking the students questions about the process as

she wrote. A student explained how to use the calculate function of the graphing calculator to

find the solution of the system of equations from the graph.

During the remainder of the lesson, Carol used the interactive white board to display

notes and examples of solving systems of equations in two variables using the elimination

method. She demonstrated the elimination process, explaining steps as she worked. After finding

an *x*-value of seven for one example, a student suggested using the table of values from the

graphing calculator to find the corresponding *y*-value.

Although students had their assigned calculators the entire class period, most of the

calculator use was for computations and reinforcing skills learned with paper-and-pencil

methods with little instruction directed toward the technology use. Carol's limited technology

uses exemplified the accepting level of TPACK development for the access theme, usage

descriptor, and the learning theme, mathematics learning descriptor. For the descriptors within

the teaching theme, however, Carol demonstrated the recognizing level of TPACK development.

During lesson study. At the beginning of the second lesson study planning meeting,

Carol excitedly reported,

> Guess what I did last week! So, we had the snow days, you know. So, I thought, "Ok,
>
> this would be the perfect time because we're not close to exams." I pulled out the TI-
>
> Navigator, and I did not practice it ahead of time. I just, I just, in fact, I put in the class
>
> names as they were walking in the door, just typing in real fast. And I said, "Guys, we're
>
> gonna try something. I don't know if it's gonna work or not." Shoot! [The students]
>
> logged in, and we figured out what we were doing. A few of them it said that there was a
>
> communication error. We figured out how to deal with that and everything. Some of
>
> them, you've gotta have good batteries because if it's any bit of a low battery, [the
>
> calculator is] not going to [respond to the signal], but we got [the batteries replaced]. First
>
> I had [the students] just log in, and I did some quick polls where they could practice using
>
> the alpha button and everything, because they've never done that. Then I even pulled up
>
> the graph and had them play. You know I'd say if you're in the first quadrant, meet me in

the second one. Boys on two, girls on four, you know. And we just practiced some things

where they could get used to it.

Later in the meeting Carol continued describing her initial use of the TI-Navigator system.

Then I clicked on equation, and I made a line. And, I said, "Type any equation that's

perpendicular to this line." You know, we had different y-intercepts and everything. So,

that was the first day [of using the system] and they were doing that. We just went crazy!

They just loved it!

Carol's decision to allow students to use the TI-Navigator system during a shortened

week of school following snow days implied the accepting level of TPACK development for the

teaching theme, mathematics learning descriptor, a level above recognizing indicated in her

TPACK Development Model Self-Report Survey and initial interview. The focus of this day of

the technology implementation was to practice using the technology, not learning about specific

mathematics topics. Although Carol engaged her students in mathematics-related activities, the

tasks were not planned to guide understanding of the mathematics concepts.

Carol was actively involved throughout the planning, observing, reflecting, revising, re-

teaching, and reflecting during the technology-based lesson study. She volunteered to teach the

revised research lesson to her Transition to Algebra students. Her input regarding her knowledge

of her students was critical in revising the lesson plan for the second lesson.

Post Interview. Carol's post interview responses revealed that although she had begun

using the TI-Navigator system along with the graphing calculators, her level of TPACK

development remained the same for the descriptors addressed. When I asked about her

experiences as a learner and as a teacher using instructional technologies, Carol stated that she

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had learned "other ways to show [the students] how to do problems" using the technology. When asked to give an example of these "other ways," Carol provided an example.

> Well, like with graphing inequalities, graphing linear inequalities, I start out by having them identify the *y*-intercept and the slope. And, we draw the slope off of the *y*-intercept and draw it and everything. But, then after they've had practice with [graphing inequalities], I have them use their calculators and [graph the inequalities], and I can do the screen shot where I can see everybody's, you know, to see right then immediately if everybody has it or not.

Carol indicated that her students graph on paper first. She commented that after they students had practice with graphing inequalities she allows them to graph using the calculators. This use of technology to reinforce concepts initially taught without technology was representative of the recognizing level of TPACK for the teaching theme, environment descriptor.

> When I asked her to describe the role that technology plays in her classroom and how her students use instructional technologies to learn mathematics, Carol described their practices.

> Each kid is assigned a calculator. As they come in the room, first thing they do is get their paper out [and] get their calculator. And, [the technology] has an important role in the classroom because they're constantly using it whether to check themselves, check backwards, or to learn new things. . . . I mean [the students], they use them to check back over their work, but also with the [TI-]Navigator, I can ask them questions off of it. [The students] can look at problems in totally different ways because of that, you know, like I showed them a couple [of] points on the screen, had them try to find the slope to that, so they had to approach [finding the slope] from a whole different way, you know,

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deconstructing the problem and trying it a different way. So, it's more than just checking

your facts. It's trying to master the concept with using [the technology] that makes it an

important tool in the classroom.

Carol's description of how her students "constantly" use the technology implied the advancing

TPACK development level for the access theme, usage descriptor. Her description of using the

technology for a different approach to learning the mathematics indicated the adapting level of

TPACK development for the access theme, barrier and availability descriptors.

Carol still expressed a desire to know more about how to integrate the technology in her

classroom effectively. When asked about her concerns regarding using instructional technology,

Carol answered,

My only concern is that there's just so much to learn, and I would love to do more things,

go to more workshops and stuff to where I could make this more effective. I'd love to do

more TI-Navigator stuff. . . . Anytime they have a [TI-Navigator] workshop, I need to be

there to learn more, because I'm sure I'm just scratching the surface as to what can be

done with those just starting out with it this year and everything. And, I want to do

everything I can do to get the kids to understand the [mathematics], because it's still just

so hard for some kids to understand it. I'm constantly looking on the Internet for - they

have all kinds of ways to teach this and that, you know, using your SMART Board and

everything, and so my only concern is that I'm not doing enough with [the technology] to

help [the students]. I mean, I'm just a student myself with technology. I need to - and

then tomorrow there'll be something new that could help them so, you know, you're

never fully up-to-date, I don't think, but you try to be.

In closing remarks Carol added the following:

> I just would like to do more of [learning how to integrate the technology]. I just (pause), I
>
> just feel like [participating in this study] got me started. And because we did this [study],
>
> I started my TI-Navigator. I was not going to start [using the TI-Navigator] even until
>
> later, because I didn't think I had time. But, now that I see that [the students] are so
>
> interested in it. I know [using the technology is] going to help me to help [the students].

Carol's desire to know more about how to incorporate the technology effectively in her lessons

exemplified the accepting level of TPACK development for the teaching theme, professional

development descriptor. Her searching online for ideas for technology integrating indicated the

exploring level of TPACK development for the curriculum and assessment theme, curriculum

descriptor.

    Classroom post-observation. Following the lesson study, I observed Carol's instruction

with a class of Algebra I students. As the students entered the classroom, Carol instructed them

to sit in one of the desks with a calculator on it and to access the TI-Navigator system using their

usernames and passwords. Carol displayed a worksheet of quadratic equations to be solved using

the quadratic formula. She directed them to determine the values to substitute into the formula.

She allowed time for the students to begin evaluating the formula before she displayed her

solution. The students used their calculators to perform computations in evaluating the formula.

As students worked, one student asked about the use of parentheses. Carol posed questions to the

class, "Does it matter whether we use parentheses or not? Can anyone tell me why it's important

to put parentheses?" One student responded, "Because you'll get the wrong answer," to which

Carol replied, "Why?" Another student said that the negative would not be in the parentheses. Carol explained the importance of using the parentheses when squaring a negative number.

Carol used the screen capture feature of the TI-Navigator system to display the screens of all of the students' calculators on the interactive whiteboard. She directed them to enter only the expression of the formula that was underneath the square root symbol, the discriminant, stating, "If you don't know how to put it in, it won't help for you to know the formula." Carol refreshed the displayed images of the students' calculator screens to allow the students to analyze each other's syntax. Some students were not finished entering the discriminant expression when she refreshed the images, so she tried to refresh again. This time, however, the computer system became nonresponsive. Carol tried briefly to correct the problem and then stated, "Let's just do it without the calculators. We're not going to let that hold us back." When she tried to return to the screen displaying the worksheet, the computer was still nonresponsive. She closed the TI-Navigator software to get the SMART Board to display the worksheet properly.

Carol continued the lesson allowing the students to use the calculators to perform computations. Rather than displaying all of the images of the screens for them to analyze each other's work, she walked around to the students' desks to observe and provide feedback about their work. Carol asked the students what approach they might take if they have multiple-choice answers and cannot remember the quadratic formula. One student suggested using the graphing calculator and storing the answer choice as the value of the variable, then typing in the expression that is given as equal to zero. The student remarked that if the calculator returned an answer of zero for the expression with the substituted value of the variable, then that value would be a solution.

Carol allowed students to choose the solution method for solving the second equation from the worksheet. She reminded students that if the value of the discriminant was equal to zero that there would be only one solution, not that the solution would necessarily be zero. Carol asked the students to graph the second quadratic equation using their calculators. She asked, "Where does it sit on the axis?" She tried to initialize the TI-Navigator system again to show the different students' screen images, but the system was taking too long. Alternatively, Carol sketched the graph of the quadratic function on the board for the students to compare to what was displayed on their calculator screens.

The lesson continued with students solving more of the quadratic equations, choosing solution methods, using the calculators for computations, and comparing their solutions with the solutions indicated by the graphs. Toward the end of class, Carol asked three students to display their work for the next three equations on the board. Some students talked with each other about their solution processes. Carol pointed out common mistakes for students to avoid.

Although Carol expressed a desire to incorporate the technology in her lessons effectively, her use of technology during her post-observation was very limited. The students used the technology to perform computations, to reinforce concepts taught without the technology, and to verify solutions found algebraically by comparing them to the graphical representations. These uses indicated the accepting level of TPACK development for the learning theme, conception of student thinking descriptor and the recognizing level of TPACK development for the teaching theme, instructional and environment descriptors. Displaying the students' screen images through the TI-Navigator system for self- and peer-evaluation was intended to allow the students to learn from each other while allowing the teacher to "tightly

manage" (Niess et al., 2009, p. 22) the instruction with the technology. Using the technology to allow students the opportunity to learn from each other implied the adapting level of TPACK for the learning theme, mathematics learning descriptor. Carol's desire to use the technology to allow control of the instruction indicated the accepting level of TPACK development for the teaching theme, environment descriptor.

Summary. "I just need more education on how to - on what to use, where to find it, how to use it. . . . I need more professional development." This statement from Carol's post-interview described her attitude throughout the study. From the beginning informational meeting, Carol indicated a desire to learn more about effectively integrating the technology. She began utilizing the TI-Navigator system in her classroom during this study and volunteered to teach the second research lesson. At the completion of the study, Carol asked for sources where she might find more professional development or ideas for utilizing the technology.

Carol's initial interview and initial classroom observation revealed TPACK development levels very different from those indicated on the TPACK Development Model Self-Report Survey. Statements from the initial interview provided evidence for the recognizing level of TPACK development for the teaching theme, accepting level for the learning theme, and adapting and advancing levels for the access theme. The initial classroom observation supported Carol's statements regarding her teaching practices with the technology, demonstrating the recognizing level of TPACK development for the teaching theme, but the accepting level of TPACK development for the access theme. The post-interview implied recognizing and accepting levels of TPACK development for the teaching theme and adapting and advancing levels of TPACK development for the access theme. The post-classroom observation provided

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evidence of the adapting level of TPACK development for the learning theme and recognizing

and accepting levels of TPACK development for the teaching theme. Figure 7 provides a

summary of TPACK development levels for Carol's case evidenced through the data gathered in

the initial and post-interviews and initial and post-classroom observations.

TPACK Summary Carol	Self-Report	Initial Interview	Initial Observation	Post-Interview	Post-Observation
Curriculum & Assessment Theme – Curriculum Descriptor	4			4	
Curriculum & Assessment Theme – Assessment Descriptor	4 & 5				
Learning Theme – Mathematics Learning Descriptor	3	2	2		3
Learning Theme – Conception of Student Thinking Descriptor	No response	2			2
Teaching Theme – Mathematics Learning Descriptor	1	1	1		
Teaching Theme – Instructional Descriptor	2, 3, & 5	1	1		1
Teaching Theme – Environment Descriptor	4	1	1	1	1 & 2
Teaching Theme – Professional Development Descriptor	2			2	
Access Theme – Usage Descriptor	4	5	2	5	
Access Theme – Barrier Descriptor	1, 3, & 4	3		3	
Access Theme – Availability Descriptor	2	3		3	

Figure 7. Summary of Carol's TPACK development levels. 1 = Recognizing, 2 = Accepting, 3

= Adapting, 4 = Exploring, 5 = Advancing.

Eric. Eric was in his thirty-first year of teaching. He earned a bachelor's degree in secondary mathematics education in 1975. He indicated that he used a "very large computer" during his educational experiences to learn computer language and write computer flow charts.

Eric had a classroom set of TI-84 plus calculators and a TI-Navigator system in his classroom. He did not have an interactive whiteboard or a projector system with which to display the computer screen for use with the TI-Navigator system. He reported that two years prior to the study, when the district was installing interactive whiteboards for the teachers of subjects that were assessed by the state, he turned down the interactive whiteboard because he did not think he would learn how to use it. Thus, although the TI-Navigator system was installed in his classroom, he had never utilized the technology in his classes.

After the first session of the Teachers as Learners phase of this study, he approached the administrator of the school asking for a projector system to display the computer screen for use with the TI-Navigator system. The administration decided to install the interactive whiteboard along with the projection system. By the end of the study, the interactive whiteboard was installed, but the projector had not yet been connected for display.

TPACK Development Model Self-Report Survey. On the TPACK Development Model Self-Report Survey, Eric indicated agreement with statements widely ranging in TPACK development levels. Although more of his responses indicated agreement with the accepting level of TPACK development, he indicated all levels throughout the descriptors. For the access theme, usage descriptor, Eric indicated agreement with both the accepting and the advancing statements. The data from Eric's TPACK Developmental Model Self-Report Survey is detailed in Figure 8. The theme and descriptor of the model are listed in the left column with the other

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columns representing the five TPACK development levels. The specific TPACK development

level self-reported is indicated with a check mark.

TPACK Self-Report Eric	Recognizing	Accepting	Adapting	Exploring	Advancing
Curriculum & Assessment Theme – Curriculum Descriptor	✓				
Curriculum & Assessment Theme – Assessment Descriptor				✓	
Learning Theme – Mathematics Learning Descriptor		✓			
Learning Theme – Conception of Student Thinking Descriptor			✓		
Teaching Theme – Mathematics Learning Descriptor			✓		
Teaching Theme – Instructional Descriptor		✓			
Teaching Theme – Environment Descriptor		✓			
Teaching Theme – Professional Development Descriptor	✓				
Access Theme – Usage Descriptor		✓			✓
Access Theme – Barrier Descriptor				✓	
Access Theme – Availability Descriptor		✓			

Figure 8. Data from Eric's TPACK Development Model Self-Report Survey

Initial interview. Eric's responses to the initial interview questions provided a different depiction of his level of TPACK development. When I asked about his experiences as a learner and as a teacher using instructional technologies, Eric's response included general descriptions.

> You can use [the graphing calculators] to check, for the kids - to let the kids check and make sure they're not making - hadn't made simple mistakes. You can use [the graphing calculators] to explain different concepts and show [the students] different things to help them understand the concepts. So, I think the graphing calculator has just been great all around for helping the kids understand better.

When I asked him to provide a specific example of how he had used the graphing calculators to help the students better understand mathematics concepts, Eric replied:

> Well, I think one specific example in Algebra I, you can help the kids understand about slope, is steepness. You know, some of the kids don't really understand steepness until you start letting them graph those lines one at a time on the calculator and just look at the steepness of [the lines], and then ask them to look back at the slope and compare the slope. And, I think that helps some of the kids understand the relationship between the steepness of the line and the slope.

Eric's description of allowing the students to use the calculators to check their work for "simple mistakes" implied the recognizing level of TPACK development for the teaching theme, instructional descriptor. Allowing the students to examine the graphs of several linear functions to understand the relationship of slope to the steepness of the line, indicated the recognizing level of TPACK development for the curriculum and assessment theme, curriculum descriptor.

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When I asked him about the role that technology plays in his classroom, Eric reiterated the idea of using the calculator to check computations and to display graphical representations.

> Well, again, basically, we use [the graphing calculators] more to check than we do as a tool to help them understand the concepts. There's very few, there's a few concepts, a few objectives we use it to understand the concepts, but most of the time, it's just a checking tool, especially in Algebra I, because I get so many students that get confused when they're working with negative numbers. . . . And, I think that's the biggest way we use it right now in class other than graphing where we use it to show [the students] - let's say if we're graphing a system and they graph it on the calculator and they can see for themselves when those two lines cross. And, I think that helps [the students] understand more that the solution is going to be where those two lines meet. . . . Other than that, we don't do a whole lot more with it right now.

These statements verified Eric's TPACK development level as recognizing for the teaching theme, instructional descriptor, and the curriculum and assessment theme, curriculum descriptor. Comments from the initial interview did not provide evidence to determine levels of TPACK development for other descriptors.

Initial classroom observation. Before the lesson study began, I observed Eric's instruction with a group of trigonometry students. As the students entered the classroom, they got their assigned calculators before being seated. Eric asked students how much of their homework they completed. Then he called on students to give their answers to homework problems. Students who had incorrect answers were called to the teacher's desk for him to examine their work and offer suggestions for correcting mistakes. Eric asked if there were other questions from

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the homework. One student asked how to work a specific problem. Eric verbally explained the steps. Then another student asked to see a specific problem worked out. Eric worked the problem on the board, explaining his steps as he wrote.

Eric assigned additional problems for students to work. He walked around the room observing students' work. Then he asked for volunteers to work two of the problems on the board. For the remaining problems, Eric asked students to call out their answers. For those problems that students had questions about, Eric worked them on the board as students called out the steps. Eric offered further explanations on problems as needed.

Eric ended the lesson by advising the students to work at least the required 30 problems to review for their test the next day. He added that if the students worked all 92 problems that they had for homework the past few days that they would not see any surprises on the test.

During the lesson, the students used the calculators for computations and finding angle measures using inverse trigonometric functions with little instruction with the technology use. One time Eric directed the students, "Now put that in your calculator and press 2nd cos." At another time in the lesson a student simplified the radical expression before entering in the calculator to find the angle measure. Eric pointed out that one advantage of using the calculator was that they would not have to simplify the radical expression first. He added, "Sometimes it makes you lazy." The technology use during this initial classroom observation indicated the recognizing level of TPACK development for the learning theme, mathematics learning descriptor, and the teaching theme, mathematics learning and instructional descriptors.

Involvement during the lesson study. During the lesson study Eric did not take a lead role in deciding tasks for the lesson plan. He took more of an active part in working through the

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details of the content for the lesson, determining equations to represent the streets and coordinates of key points to use on the map for the second lesson. He actively took observation notes during the two lessons, but added little to the debrief discussions.

Classroom post-observation. Following the lesson study, I observed Eric's instruction with a group of pre-calculus students. As students entered the room, they took their assigned calculators before being seated. Eric asked the students to put their homework problems on the board. Eric explained the homework problems and corrected students' mistakes as needed. Students also pointed out mistakes that needed to be corrected.

Following the homework discussion, Eric directed students to look at horizontal asymptotes in their books. He instructed them to graph the function given in the book as number five and make observations about the horizontal asymptotes. Eric directed the students in entering the denominator of the function in the calculator correctly. The students determined the horizontal asymptote. Eric confirmed their response and wrote the function on the board along with a sketch of the graph. Eric then directed the students to clear out function number five and enter function number six. The denominator of this function included the product of two binomials. Eric instructed the students to enter the trinomial product instead of the two binomials to avoid using double sets of parentheses. He reminded them to place parentheses around the trinomial in the denominator. He indicated to the students that he did not see a horizontal asymptote. One student questioned the appearance of the graph, asking if it should appear as three different graphs. Eric informed the student that the graph looked like a piecewise function, but that was because the window did not display the whole graph. Eric again wrote the function on the board along with a sketch of the graph.

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Eric then directed the students to enter the function from number 17 in the book. He led the students through the keystrokes as he typed the function in his calculator. He told them that the asymptote appeared to be zero on his graph. One student disagreed, but Eric informed this student that "the top one doesn't count." Again Eric displayed the function and a sketch of the graph on the board. A student asked if there was a way to determine the horizontal asymptote algebraically like they had done for vertical asymptotes. Eric told the student that he was looking for a way to do that.

For the next function, the students thought the asymptote should be 2.3. Eric told them the asymptote was actually 2 and that it only appeared as 2.3 on their calculator screens because they only saw a small portion of the graph. At this point another student asked, "So what's the pattern?" Eric responded, "I'm trying to figure it out. I thought you all could help me figure it out." Eric led the students through examining three more functions in the calculators, writing the functions on the board with a sketch of the graph. Before examining the last function, one student guessed that the horizontal asymptote had something to do with whether or not the denominator of the function was a binomial. Eric told the students that the pattern had nothing to do with whether the denominator was a binomial or not and directed them to examine the last function.

After the last function was displayed on the board, Eric told the students they had 30 seconds to find the pattern for five bonus points. One student asked Eric, "Did you figure it out?" Eric exclaimed, "I finally figured it out!" That same student responded, "It's the exponents." Without giving other students an opportunity to discuss, Eric told her that she was correct and continued teaching by reviewing the examples, pointing out the patterns in the exponents and

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how those patterns related to the horizontal asymptotes. Eric summarized the rules for using the exponents in the function to determine horizontal asymptotes.

After exploring horizontal asymptotes, Eric directed the students to work practice problems to review for the upcoming test. The students called out factors and steps as Eric worked on the board. Eric asked, "Any vertical asymptotes? Any horizontal asymptotes? Any holes [points of discontinuity]?"

Eric ended the class by acknowledging that the students seemed to understand how to find horizontal asymptotes better than students had in the past. He thanked me for helping him become more aware of how to use the technology to allow the students to discover rules for themselves.

Eric's facilitation of the technology exploration lacked some pedagogical supports, such as wait time and recording ideas from several students, which would have strengthened the discovery for more students. He was, however, beginning to practice integrating the technology as a learning tool, a change from his technology practices before the lesson study. This beginning exploration indicated the adapting TPACK development level for the learning theme, mathematics learning descriptor. The teacher-controlled environment with step-by-step instructions for the technology use implied the accepting level of TPACK development for the teaching theme, environment descriptor.

Post-interview. During his post-interview, Eric indicated to me that his views of teaching with technology were beginning to change. He also reflected on his post-observation during his post-interview. When I asked how he felt about teaching with technology, Eric explained:

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I feel that the technology can help you get points over to the students and help the

students see things for themselves instead of you just having to tell them and expect them

to go and just memorize. [The students] can kinda see things for themselves and come to

conclusions for themselves with the technology.

When I asked about his experiences as a learner and as a teacher using instructional technologies,

Eric described changes he was implementing in his technology use.

With the calculator, I have tried to use the calculator more to introduce different concepts

and let the students kinda get those concepts on their own from using the TI calculator.

. . . Well, I used [the calculators] this year to teach the concept of horizontal asymptotes,

and I think that the students comprehended more when they kinda used the calculators

and saw the different asymptotes and compared the equations. I think they got more out

of it than they did when I just told them the information and expected them to remember

the information. I think they got more out of it by seeing it for themselves. And, that's

basically so far, my experience with the [TI-]Navigators and the calculators.

I asked about the role that technology plays in his classroom. Eric's response again reflected on

his beginning exploration with technology.

Well, basically in the past, [the students] have used [the calculators] moreso as a tool to

check their work instead of a tool to learn. And, that's one of the things I think I'm trying

to get better at [is] using the . . . calculator to try to get [the students] to understand

different concepts on their own without me just having to tell them what's going on. Let

them see [the mathematics]. And, I'm trying to do more of that now, and like I did it with

the asymptote, and I'm looking for more ways to do it in Algebra I than I have done in

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the past. And, I think as I look for more ways to [allow the students to discover relationships] and come up with ideas and look at what other teachers have done with [the technology], I think [using the technology] will help my students a lot.

Eric's description of his shift in technology use from a tool to check for mistakes to a learning tool implied a positive change in his TPACK development level. His beginning to explore integrating technology as a learning tool aligned with the adapting level of TPACK development for the learning theme, conception of student thinking descriptor. Eric expressed a desire to identify other topics in his curriculum for incorporating the technology as a learning tool, but expressed difficulty in doing so, indicating the accepting level of TPACK development for the curriculum and assessment theme, curriculum descriptor. His intended quest to continue to learn and explore ideas for teaching and learning with the graphing calculators and the TI-Navigator system implied the adapting level of TPACK development for the teaching theme, professional development descriptor.

Summary. "I used to think you can't teach an old dog new tricks, but I'm starting to change my mind about that." This was a statement Eric made as students questioned his ability to learn how to use the interactive whiteboard that was installed in his classroom. Eric showed changes in his beliefs and instructional practices through this study. Having rejected the installation of the interactive whiteboard previously, Eric admittedly did not actively seek new ways to implement technology as a tool for teaching and learning. Initial interview and initial classroom observation indicated Eric's beginning TPACK level was recognizing for the curriculum and assessment, learning, and teaching themes.

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During the post-observation, the technology use was notably different. Eric was beginning to allow the students to explore the mathematics with the technology, although the facilitation of discussion surrounding the exploration was deficient. This teacher-controlled, beginning exploration implied the adapting level of TPACK development for the learning theme and the accepting level of TPACK development for the teaching theme. Statements made during the post-interview verified these TPACK levels and added the accepting level for the curriculum and assessment theme and the adapting level for the teaching theme, professional development descriptor. Figure 9 summarizes the TPACK development levels for the descriptors evidenced by data from the initial and post-interviews and initial and post-classroom observations.

TPACK Summary Eric	Self-Report	Initial Interview	Initial Observation	Post- Interview	Post- Observation
Curriculum & Assessment Theme – Curriculum Descriptor	1	1		2	
Curriculum & Assessment Theme – Assessment Descriptor	4				
Learning Theme – Mathematics Learning Descriptor	2		1		3
Learning Theme – Conception of Student Thinking Descriptor	3			3	
Teaching Theme – Mathematics Learning Descriptor	3		1		
Teaching Theme – Instructional Descriptor	2	1			
Teaching Theme – Environment Descriptor	2				2
Teaching Theme – Professional Development Descriptor	1			3	
Access Theme – Usage Descriptor	2 & 5				
Access Theme – Barrier Descriptor	4				
Access Theme – Availability Descriptor	1				

Figure 9. Summary of Eric's TPACK development levels. 1 = Recognizing, 2 = Accepting, 3 =

Adapting, 4 = Exploring, 5 = Advancing.

Gina. Gina was in her twentieth year of teaching. She earned a bachelor's degree in secondary mathematics education in 1991. Gina reported using a basic calculator in her educational experiences. In her classroom, Gina had a classroom set of TI-84 plus graphing calculators, a TI-Navigator system, an interactive whiteboard, and a TI-View Screen projected by an overhead projector.

TPACK Development Model Self-Report Survey. On the TPACK Development Model Self-Report survey, Gina ranked her TPACK as being very high. She indicated agreement with statements on the exploring and advanced levels of TPACK development for most descriptors. For the teaching theme, professional development, Gina did not mark any statement. Instead, she commented, "I have attended technology workshops already." Figure 10 provides details of the TPACK development levels indicated by Gina's TPACK Development Model Self-Report Survey.

TPACK Self-Report Gina	Recognizing	Accepting	Adapting	Exploring	Advancing
Curriculum & Assessment Theme – Curriculum Descriptor					✓ (for TI-84 calculators)
Curriculum & Assessment Theme – Assessment Descriptor				✓	
Learning Theme – Mathematics Learning Descriptor					✓
Learning Theme – Conception of Student Thinking Descriptor					✓
Teaching Theme – Mathematics Learning Descriptor					✓
Teaching Theme – Instructional Descriptor					✓
Teaching Theme – Environment Descriptor		✓			
Teaching Theme – Professional Development Descriptor	(No level marked; Comment: "I have attended technology workshops already.")				
Access Theme – Usage Descriptor					✓
Access Theme – Barrier Descriptor				✓	
Access Theme – Availability Descriptor				✓	

Figure 10. Data from Gina's TPACK Development Model Self-Report Survey.

Initial interview. Gina's responses to the initial interview questions revealed that her

TPACK development levels were lower than those indicated by her TPACK Development

Model Self-Report Survey. The descriptors addressed in the interview were in the recognizing,

accepting, and adapting levels of TPACK development. For example, when I asked about her

experiences as a learner and as a teacher, Gina described some workshops she had attended over

the years relating to implementing the graphing calculators in the classroom.

> Well, whatever I learned in the workshop, I'd try to use it in the classroom. Um, that's just
>
> like I went to a workshop back in October, and we did an activity on parallel and
>
> perpendicular lines, and I used that this week in my own class because it was so neat in
>
> the workshop, and I said, "Oh, I'm gonna use this." And, it worked out real well. The kids
>
> enjoyed it.

When I asked if she changed the task from the workshop in any way, she replied, "No, as a

matter of fact, I used their worksheets. They had a lesson planned out and problems to go over

and discuss. And I used the same [worksheet] that they gave us in the workshop." Gina's

description of implementing a technology lesson from a professional development workshop

implied the accepting level of TPACK development for the teaching theme, instructional

descriptor.

> When I asked her about the role of technology in her classroom and how her students

used the technology to learn mathematics, Gina provided general descriptions.

> Well . . . being able to visualize the graphs, and like . . . transformations, you know they
>
> can - when you change the y-intercept, what does that do to the graph? They're able to
>
> look at that on the calculator. And, reflections and all that, it makes it easier for them to

understand. . . . Just using the calculator, it makes it a lot easier to understand the

concepts.

Later in the interview when I asked her to provide specific ways the technology was used to help

the students "understand the concepts," Gina added,

Well, like I said a while ago with the transformations, they can see the shifts, the

horizontal shifts and the vertical shifts and all of that using the calculator. You can show

them, you know, a line that has a negative slope, look at the direction of the graph or a

positive slope, whatever.

Gina's description indicated that she had identified key topics for which the mathematics

concepts could be demonstrated with technology. This description of technology use implied the

adapting level of TPACK development for the curriculum theme, curriculum descriptor.

When I asked about her concerns regarding the use of instructional technologies in the

classroom, Gina responded,

Well, I just don't want them to become too dependent on the calculator. So for that

reason, I always make them show their work. I want to make sure they can do [the

mathematics] by themselves, and then use the calculator basically as checking, checking

their work.

Wanting to be sure that her students are capable of working the mathematics without the

technology was indicative of the accepting level of TPACK development for the learning theme,

conception of student thinking descriptor, and of the recognizing level of TPACK development

for the teaching theme, environment descriptor.

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Like other participants, Gina also expressed concerns about technology taking time away from mathematics instruction. When I asked about improvements she would like to occur in her implementation of instructional technologies, Gina voiced her concerns.

I'd like to use the Navigator a lot more, but it's - you know when you just have students for 50 minutes, it's hard to, you know - it's a time thing. You know, you just don't have a lot of time to do it every day, use [the technology] every day, but you know, we (pause) I just wish I had more time to be able to use it.

This concern that teaching with the technology will take time away from mathematics instruction indicated the recognizing level of TPACK for the teaching theme, mathematics learning descriptor.

As her closing remarks, Gina added, "Well, like I said, I just want to be able to use [the technology] more, and I'm gonna continue to add things, get it more into my lessons than I have in the past."

Initial classroom observation. I initially observed Gina's classroom instruction with a group of Algebra I students. Desks were arranged in groups of three with calculators connected for use with the TI-Navigator system. As they entered the room, students found their assigned seats and began working on the sample Subject Area Testing Program (SATP) item that was displayed on the interactive whiteboard. Gina instructed the students to enter their usernames and passwords to access the TI-Navigator system. Gina checked for homework as the students worked the sample test item. Students entered their responses to the test item through the quick poll feature of the TI-Navigator.

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Gina had a cup of craft sticks with students' names written on them. She randomly selected a stick to call on a student to give and explain his answer. The student she selected answered incorrectly with no explanation. Gina asked him to call on another student. The second student correctly answered and explained how he entered the function into his calculator and then looked at the table of values, in the y-column, to find the given values of the range. He knew that the corresponding x-values would be the domain values.

After the student's explanation, Gina revealed the poll summary to display how many students selected each multiple-choice answer. Nine of the students selected the incorrect answer while only five students chose the correct answer. Gina asked why so many chose the incorrect answer. The students explained that they confused domain and range. They found the given values in the x-column of the table and thought the answers would be those corresponding y-values. Gina warned the students to read questions carefully. She also demonstrated how to find the desired values of the domain without the technology by substituting in the given values of y and solving for the corresponding x-values.

Gina briefly reviewed key concepts from the previous day's lesson, graphing inequalities in two variables. Correct slope-intercept forms of the inequalities from the homework assignment were displayed on the board. Gina used the TI-View Screen projected with an overhead projector to demonstrate to the students how to use the INEQUALZ application on the TI-84 plus graphing calculators to graph the inequalities to check the graphs they had created using graph paper. She guided the students step-by-step through the process of changing the equal sign to the desired inequality symbol and displaying the graph. She guided the students

through three examples before allowing them to check the remainder of their homework graphs within their groups.

After a few moments to check their graphs from homework, Gina gave the students information about the slope and y-intercept of a boundary line, whether that boundary line is broken or solid, and whether the shading is above or below the boundary line. She asked the students to enter an inequality in their calculators that would display the given description. She used the screen capture feature of the TI-Navigator to display and compare all of the students' inequalities. She asked questions such as, "What do you notice? What does everyone have in front of the x? What does everybody have after the x?" After some discussion about the inequalities, Gina asked the students to display the graphs of their inequalities. She refreshed the screen capture display to show the students' graphs for comparison.

Gina allowed her students to create two more inequalities from given information. From the display of the students' screens, two students realized that their boundary lines were "flat" because they did not insert the x in the inequality. Gina used this opportunity to ask the students questions about the slope of horizontal lines. Another student used an equal sign instead of the appropriate inequality, so her graph displayed only the boundary line with no shading. Another student pointed out that the boundary line formed an acute angle with the x-axis. Gina pointed to the acute angle to which this student referred and pointed out that the other side of this boundary line formed an obtuse angle with the x-axis.

Gina distributed graph paper and informed the students that there was a cup at each group of desks with colored pencils and rulers for them to use. Gina guided the students through an example of graphing a system of inequalities in two variables. She graphed the system on the

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interactive whiteboard using different colors for each inequality. She asked the students, "Where they overlap, what does that show us?" The students responded that would be the region for the solutions. Gina asked the students to name some of the solutions. Students called out ordered pairs that were within the solution region. Then Gina used the TI-View Screen to demonstrate how to graph the system of inequalities on the graphing calculator using the INEQUALZ application to display only the intersection of the shaded regions. Class ended with the assignment of homework.

Gina implemented the technology throughout her lesson. The fact that all of the graphing was completed on paper as well as with the technology provided evidence for the accepting level of TPACK development for the learning theme, conception of student thinking descriptor. The teacher-directed use of the technology with step-by-step instructions supported the accepting level of TPACK development for the teaching theme, environment descriptor.

During lesson study. During the initial group planning meetings, Gina actively discussed ideas for planning the technology lesson. After the group rejected many of her ideas and the decision was made to use the street map exploration, she was not as verbal in the planning meetings. During the meeting to revise the plans after the first research lesson, Gina finally expressed her concerns in utilizing the map exploration with Transition to Algebra students. She suggested an alternative of supplying several points and allowing students to submit equations to pass through as many of those points as possible. After group discussion, the participants reached an agreement to implement Gina's idea for the initial phase of the lesson and to supplement the map exploration with purposefully selected points.

Classroom post-observation. Following the lesson study, I conducted an observation of

Gina's instruction with a group of ninth-grade Algebra I "honors" students. As students entered

the classroom, they sat at desks with calculators that were connected for use with the TI-

Navigator system. The students accessed the TI-Navigator system and entered their answer

choices for the sample SATP test that was displayed on the board. The question displayed a

sample graph of distance versus time and asked which portion of the graph indicated the fastest

speed. Gina questioned her students about their responses before displaying the quick poll

summary. All of the students indicated the correct response. Students offered sample scenarios to

go along with the graph. Gina then displayed a second sample test question for students to

submit responses. Gina selected a student's name from her cup of craft sticks to explain the

answer before displaying the poll summary. Again, all of the students indicated the correct

response.

Gina informed her students that they would be graphing scatter plots in class. She

distributed a half-sheet of paper with typed instructions of the keystrokes for graphing a scatter

plot and finding the line of best fit. Gina stated, "I'm going to go through it with you. Let's go

through the first one together. Don't get ahead of me. I know you like to do things on your own,

but let's stay together for the first one." Gina used the TI-View Screen displayed with an

overhead projector to guide the students step-by-step through the first example. She directed the

students to double-check their numbers to be sure they had typed them all in correctly.

After all of the numbers were entered in the lists, Gina guided the students to find the line

of regression. She directed them to press "CALC" and select "LinReg." Gina asked students to

make observations about the graph. One student commented that the display on the screen was

like slope-intercept form but with an "*a*" instead of "*m*." Gina guided the students step-by-step through the keystrokes to find the equation of the line of regression and enter the equation into the function window. Then she guided them step-by-step to display the graph of the scatter plot with the line of regression. Gina used the screen capture feature of the TI-Navigator to display the screens of the students' calculators. She asked, "What do you notice about the line of best fit?" The students responded that the line had a positive slope. Gina asked the students to reference the real-life problem from which the data for the problem was taken. She asked the students what the positive slope indicated in reference to the real-life context. The students replied that as time passed the temperature was increasing.

Gina instructed the students to enter the data for the second problem without her assistance. She stated, "Let me know if you need any help." One student commented, "This is so much quicker than if you had to do it on paper." Gina displayed the students' calculator screens using the screen capture. The students noticed that one graph was different. Gina asked, "What do you think might have caused that graph to be different?" The students replied that perhaps the student entered one of the numbers incorrectly in the list.

Gina instructed the students to enter data for another problem without her assistance. As students work, they commented, "Look at that!"; "This is cool!"; "I like this!"; "That's awesome!" One student commented, "Oh, it's negative." Gina noted that was a good observation. She used the screen capture feature again to allow students to analyze each other's graphs. One student's graph displayed the scatter plot but not the regression line. Gina asked questions to help the student correct the mistake. Gina asked, "What do we notice about our

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graphs?" She also asked the students the meaning of the slope of the linear regression in relation to the real-life context.

Although Gina provided the students a handout of keystrokes for creating the scatter plots and finding regression lines, she allowed student exploration without her guidance for part of the lesson. One student commented on how using the technology was so much easier than creating the graphs by hand. Using the technology allowed the students to examine and interpret three different scatter plots of data given in a real-life context in one class period. The technology allowed students access to make the connections between the data, the graphs, and the real-life context. The technology use observed in this lesson supported the adapting level of TPACK development for both descriptors of the learning theme, the environment descriptor of the teaching theme, and the availability and barrier descriptors of the access theme.

Post-interview. Gina's comments from the post-interview supported TPACK levels described from classroom observations. I asked Gina about the role that technology plays in the classroom. Gina described an instance that had occurred during that day's instruction.

> Well, like today we graphed, we used the Navigator system and the graphing calculators to graph scatter plots and, you know, there were some problems that occurred. And by using the screen capture of the Navigator system, I was able to point out, you know, and everybody was able to see the mistakes that were made, so that when [a similar mistake] happens to them, they know how to fix it. You know, like there was one student today that, she kept getting an error message when she graphed a scatter plot, but when I pulled the screen capture up and saw what was on her screen, I saw that she had not typed all of her numbers in one of the columns. And, I was kinda glad that happened 'cause I was

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able to tell [the students] how to fix it. And you know, the others were able to see that if

that [error] happens to them, you know, how to go about fixing that.

When I probed for more examples of how her students use technology, Gina continued with
other examples.

Well, like we've been graphing, finding zeros of the function in my Algebra II classes,

and [the students are] able to connect zeros of a function or solutions with the *x*-intercepts

of the graphs. They're able to see that and understand it, you know, the connection. And,

they know that if they're graphing an equation and the slope is negative, well, they've

[entered the slope as] negative, and then they graph [the line] and they - the line's going a

different direction, then they know they've done something. You know, they can

understand slope by looking at the direction of the line on the calculator.

Gina's descriptions of the different topics for which her students use technology to

reinforce mathematics concepts implied the adapting level of TPACK development for the

curriculum and assessment theme, curriculum descriptor. The description of using the screen

capture feature of the technology to identify and correct mistakes supported the teacher-

controlled, step-by-step instructions of the accepting level of TPACK development for the

teaching theme, environment descriptor.

I asked Gina about her concerns with using instructional technology in the classroom.

Gina expressed her desire for her students to be able to "do" the mathematics without the

technology.

Well, I don't want them to become too dependent on it. Usually, on most things, we do it

on paper first and then we go to the technology and, you know, they can see the

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connection. Because, you know, they do need to know how to do it without, without technology. The technology's mainly there just to help them understand what we're trying to do on paper. But yeah, I don't want them to be too dependent on the calculators.

Gina's concern of her students becoming dependent on the technology and her indication of introducing topics without the technology indicated the accepting level of TPACK development for the learning theme, conception of student thinking descriptor, and the recognizing level of TPACK development for the teaching theme, environment descriptor.

Summary. "There's still a lot that I don't know how to do, but I feel a lot better using it in the classroom now." Gina made this statement in referring to her feelings about using technology and how her feelings had changed throughout her career. Gina was the only participant who implemented the TI-Navigator system in both of her classroom observations. Regarding her experience during the lesson study, Gina commented, "I just stayed quiet because I was - I said, 'Well, um, I don't want to seem like I'm a know-it-all or anything.'" Although Gina was the team leader for the mathematics department at the high school, she expressed that after the group rejected her original ideas for the lesson plan, she chose to remain quiet and allow the others "to do it the way they thought it should be done." Her decision to express her feelings in revising the lesson led the group to make changes that allowed access to the mathematics exploration for the Transition to Algebra students.

Gina's individual case indicated some gains in TPACK development. Gina's initial interview and initial classroom observation indicated TPACK development levels primarily at the accepting level. Post-interview and post-classroom observation, however, provided evidence for the adapting level of TPACK development for several descriptors. Figure 11 provides a

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summary of the TPACK levels evidenced in Gina's case from the initial and post-interviews and the initial and post-classroom observations.

TPACK Summary Gina	Self-Report	Initial Interview	Initial Observation	Post-Interview	Post-Observation
Curriculum & Assessment Theme – Curriculum Descriptor	5 (GC)	3		3	
Curriculum & Assessment Theme – Assessment Descriptor	4				
Learning Theme – Mathematics Learning Descriptor	5				3
Learning Theme – Conception of Student Thinking Descriptor	5	2	2	2	3
Teaching Theme – Mathematics Learning Descriptor	5	1			
Teaching Theme – Instructional Descriptor	5	2			
Teaching Theme – Environment Descriptor	2	1	2	1 & 2	3
Teaching Theme – Professional Development Descriptor	No response				
Access Theme – Usage Descriptor	5				
Access Theme – Barrier Descriptor	4				3
Access Theme – Availability Descriptor	4				3

Figure 11. Summary of Gina's TPACK development levels. 1 = Recognizing, 2 = Accepting, 3

= Adapting, 4 = Exploring, 5 = Advancing.

Summary

The goal of the technology-based lesson study was to plan a lesson collaboratively to improve students' understanding through utilizing the TI-Navigator system and the TI-84 plus graphing calculators. Working toward this goal in the lesson study compelled the participants to interact within higher levels of the TPACK development model. Through the whole-group interactions, the participants examined their curriculum, exploring topic areas and searching for ideas about integrating the technology, displaying adapting and exploring levels of TPACK development for the curriculum and assessment theme. The design of lesson study also required the participants to plan, implement, reflect on, revise, and re-teach the technology-based research lesson. The goal throughout the lesson study was to increase students' understanding. In carrying out these actions, the group of participants displayed the exploring and advancing levels of TPACK development for the learning theme. By working together to create and implement the exploration-based technology lesson, the group exemplified the adapting and exploring levels of TPACK development for the teaching theme.

Individual case studies revealed that although the participants exemplified these higher TPACK development levels through the lesson study, the individual beliefs about learning with technology and teaching practices with technology varied. The impact of the lesson study on individual's TPACK development also varied. Beth, who played an extremely active role in planning and implementing the technology lessons, remained at recognizing levels in her own classroom practices. Carol, who taught the second research lesson, reported changes in TPACK development during her post-interview and implemented the technology as a learning tool, although briefly, during her post-classroom observation. Eric, who was not as active in creating

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the plan but was instrumental in the content issues involved in the plan, demonstrated a shift

from utilizing the technology as a tool for checking computations to a tool for exploring the

mathematics for learning. Gina, who was quiet through much of the lesson planning,

demonstrated a shift from step-by-step directed technology use to allowing some exploration of

mathematics during the lesson. The progression of the individual mathematics teachers through

the TPACK development with respect to the educational and technological backgrounds and

experiences will be discussed in the next section.

TPACK Development With Respect to Backgrounds and Experiences

Niess et al. (2009) called for examining how teachers' rate of progression through the

levels of the TPACK Development Model for a particular technology compares with respect to

their TPACK Development for other technologies. Although my study did not investigate

TPACK development levels for other technologies, I was also interested in how teachers'

progression through the levels of the TPACK Development Model compared with respect to

their previous experiences with technology. The second research question of my study was,

"How do teachers' progression through the stages of TPACK development compare with respect

to their educational and technological background experiences?" Information from the Survey of

Technology Use and Educational Background along with the evidence of TPACK levels served

to address this question.

Educational Backgrounds and Technology Use

The educational backgrounds and technological experiences of the participants varied.

Carol, Dana, Eric, and Gina reported minimal technology use in their educational experiences.

Their use of technology included computer programming and basic calculators. Amy and Beth,

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who both graduated high school and college in the twenty-first century and were enrolled in graduate-level programs for master's degrees, reported more technology use in their educational experiences. They both reported using graphing calculators, although minimally, in high school and college mathematics classes. Amy even noted the use of the TI-Navigator system in her student-teaching experience. Amy and Beth also reported the use of PowerPoint presentations, Internet resources, and online class components during their educational experiences. Table 3 provides details of the educational backgrounds and the reported use of technology in those educational experiences.

Table 3

Educational Backgrounds and Technology Use in Educational Experiences

Pseudonym	Educational Background	Technology Use
Amy	B.S. (2008) in secondary mathematics education; working on master's degree in teaching English as a second language	Graphing calculators (high school & college), Microsoft Office, Geometer's Sketchpad, Internet resources, online classes, document presenter, TI-Navigator system
Beth	B.S. (2007) in secondary mathematics education; final semester in master's program for secondary mathematics education	Graphing calculators (high school & college), Microsoft Office, Internet resources, online classes,
Carol	B.S. (1993) in elementary education	Computer programming, calculators, video, overhead projector
Dana	Bachelor's degree in electrical engineering (1980)	Calculators, calculator programming
Eric	B.S. (1975) in secondary mathematics education	Computer language and flowcharting
Gina	B.S. (1991) in secondary mathematics education	Basic calculator

The Survey of Technology Use and Educational Background also gathered data regarding the participants' personal use of technology. The personal use of technology compared similarly to the experiences of technology in educational backgrounds. That is, those participants who reported using technology more in their educational backgrounds also reported using technology more in their personal lives. In addition, the Survey of Technology Use and Educational Background gathered information of the participants' use of technology in their

classrooms, which also varied. Table 4 provides details of the participants' reported technology

use in their personal lives and in their classrooms. The purpose indicated for which the

technology was used is included in parentheses.

Table 4

Technology Use in Personal Lives and in Classroom

Pseudonym	Technology Use in Personal Life	Technology Use in Classroom
Amy	iPhone (communication), iPod (entertainment), Internet social networking, email, Internet banking/bill pay	TI-84 graphing calculators (general computations), Microsoft Office (daily lesson presentations), projector (display), school computer network (gradebook, lesson plans)
Beth	iPhone (communication/fun), social networking, email, Blackboard (university course management), Microsoft Office (lesson plans, graduate work)	Internet resources (research, USAtestprep), TI-Navigator system (occasional lessons), TI-84 graphing calculators (graphing, computation), SMART Board (presentation), Microsoft Office (lesson presentations)
Carol	iPod/iPad (entertainment, email, word processing, social networking, Netflix, lesson planning, bill pay)	TI-84 graphing calculators (teaching/learning concepts, checking work), TI-Navigator system (enrich lessons), SMART Board (display, enrichment)
Dana	Calculator, email (networking, communication), iPhone (fun), Google (search), word processing (lesson plans, worksheets)	TI-84 graphing calculators (computation), overhead projector (display)
Eric	Internet (play chess)	TI-84 graphing calculators (check work)
Gina	Internet (online banking, social networking, email)	TI-84 graphing calculators (graphing, computations), TI-Navigator system, SMART Board (display), overhead projector (display), TI-84 View Screen (display)

Progression in TPACK Development

The more recent college graduates and only participants enrolled in graduate programs at the time of the study, Amy and Beth, reported the most technology use in their educational experiences, in their personal lives, and in their classrooms. Amy and Beth took lead roles in the lesson study. Amy was the group secretary who recorded notes of each meeting, typed up ideas and the lesson plan, and often redirected the group conversations to keep the participants on task in planning the lesson. Both Beth and Amy took lead roles in the discussions that led to the initial lesson plan idea of using the street map exploration. Beth searched and found different map images for the group to examine and operated the technology during all of the group meetings as well as during both research lessons. Beth and Amy also took on the task of creating the map images with the grid and points overlay to distribute to the students in the second research lesson. The whole-group interactions revealed through the lesson study exemplified higher levels of TPACK development. The TPACK development levels progressed as the lesson study progressed.

Interestingly, pre- and post-classroom observations for both Amy and Beth evidenced recognizing levels of TPACK development. Their use of technology was primarily for computation purposes, displaying graphs, or substituting values into programs to find values of slope or distance. There was little instruction relating to the technology use. Both Amy and Beth used display technologies extensively in their lessons. They displayed notes and examples with PowerPoint presentations.

The other four participants made changes, although some minimal, from the initial classroom observation to the post classroom observation. For initial observations, Carol, Dana,

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and Eric allowed the students to use the TI-84 graphing calculators primarily for computations and displaying graphs. For the post-observation, Carol attempted to incorporate the TI-Navigator system during the lesson for the post-observation. Due to technology failure early in the lesson, however, she continued the lesson using the TI-84 graphing calculators. For her post-observation lesson, Dana planned to allow students to calculate discriminants of different quadratic equations and examine their graphs to make generalizations about the number and types of solutions. Due to time restraints, however, the students were only able to perform the calculations during the post-observation. Dana announced to the class that they would examine the graphs the next day. For his post observation, Eric guided students to examine the horizontal asymptotes of different functions and make generalizations about the relationships of the horizontal asymptotes to the exponents in the function. Gina implemented the TI-Navigator system in both her pre- and post-observations. Her implementation during the post-observation, however, allowed exploration by the students during a portion of the class time, a change from the initial observation.

The TPACK development levels exemplified during initial and post-observations for Dana were unchanged. Both observations revealed recognizing TPACK levels with the limited use of the technology for computations. Carol's technology uses during the initial classroom observation demonstrated the recognizing TPACK development level for the teaching theme and accepting TPACK development level for the learning theme. Carol's post-classroom observation exemplified recognizing and accepting levels within the teaching theme and accepting and adapting levels within the learning theme. Eric's TPACK development levels from the initial observation were recognizing with the calculators used for computations. Eric's post-observation, however, revealed accepting and adapting TPACK development levels. TPACK

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development levels exemplified in Gina's initial observation were at the accepting level, while her post-observation revealed adapting TPACK levels.

Summary

Data gathered by the Survey of Technology Use and Educational Background along with the TPACK development levels evidenced from the initial and post-observations offered interesting findings. The participants with more reported technology use in their educational backgrounds, classrooms, and personal lives, Amy and Beth, showed no progression from the recognizing levels in TPACK development in their individual cases. These participants, however, took lead roles in the lesson study in which the whole-group interactions revealed higher levels of TPACK development. The other four participants, who reported little technology use in their educational backgrounds, made changes in their technology use from initial observations to post-observations. These changes in technology use revealed changes in TPACK development levels for three of the participants: Carol, Eric, and Gina. Interestingly, Eric and Gina reported the least amount of technology use in their personal lives.

Supports Perceived as Important to TPACK Development

Interactions with participants in the 2008 – 2010 study prompted my interest in determining the supports that secondary mathematics teachers perceive as important to facilitate TPACK development. During that study, many of the participating teachers reported little use of the TI-Navigator system despite professional developments and one-on-one support. I used data gathered from writing prompts after the Teachers as Learners phase and the Lesson Study phase along with comments from interviews to address the third research question of this study, "What

supports do secondary mathematics teachers perceive as important in facilitating TPACK development?"

Teachers as Learners Phase

The participants completed writing prompts at the end of the Teachers as Learners Phase (see Appendix E). The participants ranked the effectiveness of different aspects of the professional development sessions in shaping ideas about effective integration of technology in a mathematics classroom. All of the participants ranked "Participating as a learner in a technology task" as having "great effect" on their ideas about effective technology integration. The participants ranked other aspects of the professional development sessions as having "little effect" to "great effect" on shaping their ideas of effective technology integration. Table 6 summarizes the aspects of the professional development sessions and the number of participants who designated each rank. Ranks are listed as column headers. The number of participants assigning each rank is indicated in cells of the table.

Table 5

Numbers of Participants Assigning Each Rank of Effectiveness for Aspects of Professional Development Sessions

	Effectiveness Ranks			
	1	2	3	4
Participating as a learner in a technology task				6
Discussing pedagogical and technological issues related to the task		1	1	4
Predicting students' thinking through the technology task		1		5
Observing the technology lesson via video			2	4
Analyzing and debriefing the technology lesson			1	5

Note. Ranks were indicated as: 1 = did not affect my thoughts about technology integration, 2 = little effect, 3 = some effect, 4 = great effect.

Participants also wrote responses to describe their thoughts about effective integration of technology in a mathematics classroom. In these written responses, the participants provided support for the aspects of the professional development that were beneficial in shaping their beliefs about effective technology integration. Dana's response included, "The experience with the technology is what convinces me that it will be beneficial in a classroom." Eric wrote, "I think effective integration of technology in a mathematics classroom can occur only after you try different methods in your classroom or observe lessons tried by others and change [those lessons] to relate to your students." Amy also described aspects of the Teachers as Learners phase that served to encourage technology use.

I truly enjoyed watching the lesson of graphing lines using the Navigator system. The

students really seemed to be involved with each step of the lesson. It is hard for teachers

to try something new – however, this integration of technology only discourages the fear

of attempting to change the classroom environment, and encourages the use of

technology in the classroom.

Lesson Study Phase

The participants also completed writing prompts at the end of the Lesson Study Phase

(see Appendix F). The participants ranked the effectiveness of the different aspects involved in

the lesson study in shaping their ideas about the effective integration of technology in a

mathematics classroom. Participants' ranks varied from "little effect" to "great effect." Table 7

summarizes the ranks of the different aspects of the lesson study. The ranks are listed as column

headers with the number of participants indicating that rank within the cells of the table.

Table 6

Numbers of Participants Assigning Each Rank of Effectiveness for Aspects of Lesson Study

	Effectiveness Ranks			
	1	2	3	4
Discussing mathematical goals for lesson study		1	1	4
Discussing pedagogical issues (devising good questions, predicting student responses and/or misconceptions, etc.) related to the lesson		2	2	2
Discussing technological issues (when/how to use the technology, how to manage unexpected technical difficulties, etc.) related to the lesson			2	4
Observing the first technology lesson		1	1	4
Analyzing and debriefing the first technology lesson		1	2	3
Revising the technology lesson plan		1	2	3
Observing the second technology lesson			2	4
Analyzing and debriefing the second technology lesson			1	5

Note. Ranks were indicated as: 1 = did not affect my thoughts about technology integration, 2 = little effect, 3 = some effect, 4 = great effect.

The participants also wrote responses to describe their thoughts about effective integration of technology in a mathematics classroom. Eric indicated a desire to continue planning with other teachers. He wrote, "I think to effective[ly] integrate technology in a mathematics classroom, teachers need more time to plan and longer class periods to implement the plan." Carol's response was similar to Eric's. She responded:

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I have learned a lot about integration of technology into my math classes as a result of participating in the lesson study process. I wish we could share a planning period, which would allow us more time to do this with future lessons. [Participating in the lesson study] has certainly [shown] me that my lessons can benefit from using TI-Navigator.

Supports Indicated in Interviews

The participants also made comments during interviews regarding supports they felt were important to support development of effective technology integration. In her post-interview, Carol expounded on her desire to continue working with other teachers in planning technology lessons.

I wish that - you know, we talked that it would be great if we could all have the same planning period so that it wouldn't be just a one-lesson thing, it would be a daily kind of thing that we could do. And, I've worked at schools where you did, you had team planning periods. And you know, I think it would be very beneficial, especially for any of us who have a problem, you know, teaching something like slope, for example. . . . I thought that was a great experience being able to work with the other teachers, and you know it always - it always gives you ideas of what you can do in your room when you hear the other [teachers] talk and everything.

In her closing remarks for the post-interview, Carol added,

I just would like to do more of it. I just feel like [participating in the study] got me started. And because we did this, I started [using] my TI navigator. I was not going to start [using the TI-Navigator] even until later, because I didn't think I had time, but now that I see that [the students] are so interested in it, I know it's gonna help me, you know,

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to help them. . . . I thank you for coming because I wouldn't have [started using the TI-Navigator system] that early without it. And I just (pause) I just really liked it, you know, and I need to learn more though.

Dana indicated that participating in the lesson study made her more aware of her own planning practices. In her post-interview, Dana explained:

The degree that we did [the planning] to was kinda (pause) kinda (pause) kinda overwhelming. I think it's helpful to [plan collaboratively] every now and then because I do think it makes you pay a little more attention. I think [participating in the lesson study] made me pay a little more attention to what I'm doing in my lesson plans since then.

Dana further commented about the motivation she received from working with other teachers. Her comments indicated that collaboration with other professionals is important to her own professional development.

Anytime I go to a workshop or anytime I deal with other people like this, it kind of (pause) motivates me to do a little bit better. You know, it's kinda nice to be involved with other people and get their aspects of things and see that somebody - you come in with some, maybe some new ideas or new way of looking at things, and it just kinda makes you a little more energized about your subject. . . .When I sat in on that one class, you know, watching the kids respond to the [TI-]Navigator and getting - you know, they started off real cold and not doing a whole lot and then slowly got more involved. And eventually, you know, a couple got pretty, "Oh yeah, look!" . . . So, that was fun to see how engaged the kids got, so I thought that was neat.

During his post-interview, Eric made several comments that documented the important role that participation in the lesson study played in facilitating his own TPACK development. When I asked him about factors that influenced his decisions to use or not use available instructional technologies, Eric replied:

Well, the biggest factor is that - that affected my decision to use [the technology] was seeing other teachers at the school use the [TI-]Navigator and just seeing how (pause) how their students kinda respond to it. Just from looking in their classroom and seeing their students use it and seeing how (pause) how it kept the students' attention while they [were] using that technology. I think you keep those students' attention more when you use the technology than you can without the technology. That was the biggest factor, and along with going to a [TI-]Navigator workshop myself, and being a part of that workshop myself. And, it was interesting to me, so I felt like it would be also with my students. They would be more interested using the technology than without the technology. And that was the biggest factor that made me decide to come on, I guess, into the 21st century.

Eric further explained that he thought of the lesson idea that he implemented during his post-classroom observation while observing other students use the technology. He explained:

That idea came to me when we planned the lesson, on the [TI-]Navigator for the Algebra and the transition class. And it just kinda hit me then . . . from seeing [those] kids seem to be understanding more, so (pause) and it just kinda came to me from that, that I could do similar things in pre-calculus with the calculator and that's kinda where I got that idea from, just from seeing, seeing other people use other type[s] of technology.

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Summary

The participants indicated that they perceived all of the aspects of the Teachers as Learners phase and the Lesson Study phase as having some effect in shaping their ideas about effective integration of technology in mathematics classroom. All of the participants noted that "Participating as a learner in a technology task" had a great effect in shaping their ideas. Written comments indicated that viewing the video of a technology lesson with the TI-Navigator also served to discourage the fear of changing the classroom environment. Written comments and comments from post-interviews provided evidence that the participants viewed the collaborative planning and observing other teachers as important supports for facilitating TPACK development. Several of the participants expressed a desire to have a designated time to continue collaborative planning.

Summary

The design of lesson study involves collaboratively planning, implementing, reflecting on, revising, re-teaching, and revising a detailed lesson with the goal of increasing students' understanding. Because these actions are representative of actions in higher levels of the TPACK Development Model (Niess et al., 2009), participation in the technology-based lesson study required participants to interact with each other in ways that were supportive of the adapting, exploring, and advancing levels of TPACK development. Individual TPACK levels, evidenced by data gathered before and after participation in the technology-based lesson study, varied. Some of the participants experienced positive changes in their TPACK levels, while others' TPACK development levels remained the same.

Interestingly, the two participants with more technology use reported in their educational backgrounds did not show evidence of progression in their TPACK development from the initial classroom observation to the post-observation. The four participants with less technology use reported in their educational backgrounds produced changes in their observed lessons, although the changes of only three of these participants indicated progression in TPACK development, two of whom reported the least amount of technology use reported in their personal lives.

Inservice mathematics teachers need supports to facilitate their professional growth (Hiebert, 2003; NCTM, 2007). To facilitate TPACK development, the participants perceived "participating as a learner in a technology task" as important. Collaboratively planning and observing technology lessons were also documented as supports perceived as important in supporting TPACK development.

CHAPTER V: DISCUSSION AND IMPLICATIONS

Introduction

Technological, pedagogical, and content knowledge (TPACK) is the intersection of three types of knowledge needed for teaching: knowledge of content, knowledge of pedagogy, and knowledge of technology. In fall 2007, educational leaders at the National Technology Leadership Initiative changed the acronym from TPCK to TPACK, noting that TPACK is not just about integrating technology. Rather, TPACK is "the total package required for truly integrating technology, pedagogy, and content knowledge in the design of curriculum and instruction preparing students for thinking and learning mathematics with digital technologies" (Niess, 2008, p. 10). In 2009, Niess et al. comprised a set of TPACK standards for mathematics teachers along with a TPACK development model for mathematics teachers. The development model described stages through which teachers with established pedagogical content knowledge (PCK) progress as they develop TPACK for specific technologies.

The more advanced levels of TPACK development include practices such as designing, implementing, and reflecting on technology lessons with a concern for students' understanding (Niess et al., 2009). These practices are the main components of lesson study, a professional development model with a focus on improving instructional practices to improve students' learning. Lesson study research (C. Fernandez, 2005; M. Fernandez, 2005; Perry & Lewis, 2009; Taylor et al., 2005) indicates that lesson study provides opportunities for teachers to increase their PCK, the foundation for TPACK development. Additionally, TPACK research utilizing

components of lesson study (Lee & Hollebrands, 2008; Richardson, 2009) has promoted development of preservice and inservice teachers' TPACK.

With the TPACK Development Model (Niess et al., 2009) as the theoretical framework used as a lens for data analysis, this study examined the impact of participating in a technology-based lesson study on the TPACK development of inservice secondary mathematics teachers. More specifically, this study addressed the following research questions:

1. How does participating in lesson study emphasizing the use of TI-84 graphing calculators and the TI-Navigator system impact secondary mathematics teachers' TPACK?

2. How do teachers' progression through the stages of TPACK development compare with respect to their educational and technological backgrounds and experiences?

3. What supports do secondary mathematics teachers perceive as important in facilitating TPACK development?

This chapter will provide a discussion of the findings and implications from this study. The first section will contain a discussion of the findings as related to the research questions. Next, a discussion of factors affecting the study will be presented. Finally, implications of this research as related to the mathematics education community will be discussed.

Discussion of Findings

The focus of this study was to examine the impact of participating in a technology-based lesson study on inservice secondary mathematics teachers' TPACK development. Whole-group interactions exemplified the higher levels of TPACK development (adapting, exploring, and advancing) while the individual cases revealed primarily lower levels of TPACK development

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(recognizing, accepting, and adapting). The design and goals of the technology-based lesson study compelled the participants to perform within the higher levels of the TPACK Development Model while working collaboratively on planning, carrying out, analyzing, and revising the technology lesson. These group interactions caused some individual participants to examine their own practices and begin to explore different technology uses and pedagogical practices. Through interview responses and writing prompts, all of the participants indicated learning more about effectively integrating technology with a desire to utilize similar practices in their mathematics classrooms. Only four of the post-classroom observations, however, revealed changes in practices of technology use. Although four of the post-classroom observations revealed changes in technology use, only three of these post-classroom observations provided evidence of positive changes in TPACK development.

Of the instructional changes noted in classroom observations, some were related more to pedagogy than to technology implementation. More use of open-ended questions and explorations followed by students making generalizations were evidenced in the post-observations. These changes implied that participation in the technology-based lesson study served to promote the participants' PCK, the underlying foundation of TPACK. This finding supports earlier research that reported participation in lesson study provides opportunities to promote PCK (C. Fernandez, 2005; M. Fernandez, 2005; Perry & Lewis, 2009; Taylor et al., 2005). Such changes in instructional practices, similar to those promoted by Stigler and Hiebert (1999), are vital to the improvement of the mathematics achievement of U.S. students.

With respect to the participants' education and technology backgrounds, the two participants who reported the most use of technology during their educational experiences took a

lead role in designing, planning, and reflecting on the research lessons for the lesson study. Both of these participants completed bachelor's degrees in the twenty-first century. Their lead roles in designing the exploration lesson indicated familiarity with current trends in mathematics education, likely a result of their recent completion of a teacher preparation program. They did not, however, show changes in their instructional practices during the classroom observations.

Initial and post-classroom observations of both of these participants included the display of PowerPoint presentations with notes, examples, and applications of the mathematics topics under study. Both of these participants mentioned their use of PowerPoint presentations during their interviews when asked how they felt about teaching with technology. Although they were using technology in the classroom, the technology was not utilized for the purpose of student learning.

As Stigler and Hiebert (1999) pointed out, teachers teach the way they were taught. Having completed their undergraduate programs of study more recently than the other participants, these two participants received training in teacher education classes that promoted and utilized various technologies for display purposes. Teacher preparation programs should consider the purpose of their technology integrations and adjust technology, content, and/or methods classes to provide opportunities for preservice teachers to learn through technology. As one option for preparing teachers to integrate technology effectively, Cavin (2007) reported that participation in technology-based Microteaching Lesson Study (MLS) promoted TPACK in preservice secondary mathematics teachers.

The third research question sought to determine the supports that participants perceived as important to facilitate TPACK development. The writing prompts used in the study asked the

participants to rank the components of the professional development sessions and the lesson study in terms of the effectiveness in shaping their ideas of effective technology integration in a mathematics classroom. The writing prompts also asked the participants to describe their beliefs about effective integration of technology in a mathematics classroom with respect to those components. On the writing prompt following the Teachers as Learners Phase, all of the participants ranked "Participating as a learner in a technology task" as having a "great effect" on shaping their beliefs about the effective integration of technology within a mathematics classroom. NCTM (2007) stated that teachers need to experience learning in an environment that "incorporates technology in a meaningful way" (p. 19).

Writing prompt and interview responses also documented that the participants perceived observing and analyzing technology lessons as important in supporting their TPACK development. On the writing prompts, the participants ranked observing and analyzing the lessons as having "some effect" or "great effect" on their beliefs about the effective integration of technology in a mathematics classroom. Amy also noted that observing the technology lesson via video helped alleviate "the fear of attempting to change the classroom environment." Eric indicated that observing the students' engagement in the technology lesson during the lesson study encouraged his own exploration in using technology as a learning tool in his classroom. Prior research demonstrated the positive impact of observing and analyzing technology-based lessons (Cavin, 2007; Lee & Hollebrands, 2008) on the TPACK development of preservice and inservice teachers.

Several of the participants also indicated that they desired more time for collaboration and intensive planning. Calls for reform in mathematics education have been echoing for decades

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(ISTE, 2000, 2002, 2007, 2008; NCTM, 1989, 1991, 2000, 2007; Stigler & Hiebert, 1999) with little changes in practices. With the positive effects of lesson study shown by previous research (C. Fernandez, 2005; M. Fernandez, 2005; Perry & Lewis, 2009; Taylor et al., 2005) and the finding from this study that participation in a technology-based lesson study allows opportunities to practice higher levels of TPACK development, administrators should consider providing supports for teachers interested in such collaborative planning efforts. Other researchers (Stigler & Hiebert, 1999; Taylor, 2005) have suggested support from administrators for lesson study efforts, such as common planning time, extra planning time, and substitute teachers for days away from class.

As another means to gather data for the third research question, one interview question asked participants how their feelings about teaching with technology had changed during their careers. This question was intended to provide details about the factors, other than those involved in this study, which had prompted changes in TPACK development. Most of the interview responses, despite probing, did not detail specific supports that facilitated changes in beliefs about effective technology integration, and as a result, TPACK development. Thus, the only supports examined for the third research question were components of this study.

Discussion of Factors that Affected the Study

The previous section provided discussion of the findings of the study. There were factors, however, that may have impacted those findings. The factors that potentially affected the findings of the lesson study are discussed in this section.

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Teachers as Learners Phase

The Teachers as Learners phase of this study was critical to prepare the participants for engaging in the lesson study. This phase offered opportunities for the participants to engage as learners in technology tasks. In addition, this phase allowed the participants to predict students' thinking through similar tasks, observe a technology lesson, and reflect on the lesson analyzing students' understandings. Although four of the six participants had participated in learning experiences using the TI-Navigator system during the 2008 – 2010 study, they had not experienced observing and analyzing a technology lesson, two aspects of the Teachers as Learners phase designed to prepare the participants for the lesson study. Previous research indicated the need for teachers to participate as learners with technology (Hiebert, 2003; NCTM, 2007) as well as positive impacts on teachers' TPACK from observing and analyzing technology-based lessons (Cavin, 2007; Lee & Hollebrands, 2008).

Responses from the writing prompts administered between the Teachers as Learners phase and the Lesson Study phase were intended to give insight into the participants' TPACK levels as a result of participating in the professional development portion of the study. The written responses asked participants to relate their beliefs about the effective incorporation of technology in the mathematics classroom to their experiences with the various components of the Teachers as Learners phase. The majority of the participants' responses, however, addressed general beliefs about effective integration of technology, which provided no evidence for determining TPACK development levels. With no other data gathered at this point of the study, I was unable to determine the TPACK development levels of the participants for the transitional period between the Teachers as Learners phase and the Lesson Study phase. Thus the individual

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changes in TPACK development that resulted from this study may have been partially due to the participation in the Teachers as Learners phase and not solely a result of participation in the technology-based lesson study.

Lesson Study Implementation

This was the first lesson study experience for the participants. Stigler and Hiebert (1999) noted that teaching is a cultural activity. The teachers who participated in this study were not accustomed to writing lesson plans with the amount of detail normally included in a research lesson. For example, Dana noted that the depth of the lesson study was "overwhelming." As a result, despite prompting from the university faculty reviewer and from me as the facilitator, the participants' lesson plan contained an outline of the lesson with general comments for the teacher to remember. The plan did not contain detailed questions to ask the students to uncover the mathematics being explored or to guide those students who might struggle with the task.

Additionally, this study only examined the impact of participation in one cycle of lesson study. Hiebert (2003) specified that an important feature of effective professional development is an "ongoing collaboration – measured in years – of teachers for purposes of planning" (p. 19). Perry and Lewis (2009) documented struggles of the lesson study during the first year of implementation within a California school district. During the first year of implementation, the goal of the lesson study was the improved lessons themselves. District administrators and participants learned from their own practice and made adaptations to the lesson study model to emphasize teacher development. The findings reported in this study reflect the results of this initial lesson study practice, not those of more accomplished lesson study participants.

Timing

Another factor that possibly contributed to limited TPACK levels evidenced in this study was the timing of the study. Because the lesson study was conducted during the second half of the school year, the participants had already taught most of the topics for which the graphing technology serves to promote understanding. If the Teachers as Learners phase had been conducted in the summer months with the lesson study starting early in the school year, the participants could have examined their entire curriculum for areas in which improvement was needed and for which the graphing technology could have promoted the students' understanding through exploration in introductory lessons. With the lesson study conducted during the second semester, however, a topic was selected that had previously been taught, thus limiting the level of TPACK development for the teaching theme. Additionally, due to timing within the school year, the delayed post-observations and delayed post-interviews were eliminated from the methodology of the study.

Data Sources

Data was gathered from several sources for this study. On the TPACK Development Model Self-Report Survey the participants tended to rank themselves at higher levels of TPACK development than the classroom observations evidenced. Previous research has shown that self-reported data is often biased and overstated (Ivy, 2011; Kopcha & Sullivan, 2006; McCrory, 2010). With the expectation that participants' responses to the statements on the self-report survey would indicate higher TPACK development levels, the interview protocol was designed to probe for more information regarding the participants' use of technology. The participants used terminology in their interview responses that would indicate possible higher levels of

TPACK development. Upon probing, some of the specific examples that participants provided supported lower levels of TPACK development than initially implied by more general interview responses. Often the participants were unable to describe a specific example or supplied additional general descriptions, using key phrases such as "understanding concepts." The classroom observations provided a more clear determination of TPACK levels, especially considering the definition of TPACK proposed by Cox (2008) that specifies "a classroom setting" (p. 51).

The writing prompts completed after the Teachers as Learners Phase and after the Lesson Study phase were intended to reveal participants' perceptions about supports that were important in developing TPACK. Additionally, the writing prompt completed at the end of the Teachers as Learners Phase was expected to provide evidence of TPACK development that might have resulted from participating in the Teachers as Learners phase prior to entering the Lesson Study phase. The participants' responses to these writing prompts did not provide evidence of their TPACK development levels, as intended. Therefore, although some supports perceived to be important to the participants were mentioned, I was unable to pinpoint if these supports served to promote TPACK. Additionally, I was unable to determine TPACK development that might have occurred as a result of participation in the Teachers as Learners phase prior to entering the Lesson Study phase.

Implications and Recommendations

The findings from this study provide implications that are important considerations for the mathematics education community. Phenomena from this study also provide

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recommendations for future research. These implications and recommendations for future

research are discussed in the sections that follow.

Lesson Study as a Means to Promote TPACK

This small-scale, qualitative study indicated that participating in a technology-based

lesson study provided opportunities for practicing actions from higher levels of the TPACK

Development Model within the lesson study group, thus offering potential for promoting

TPACK development for individual teachers. Although changes in TPACK development varied

for individual cases, during the group meetings of the Lesson Study phase, the participants

interacted in the higher levels of TPACK development. As the lesson study progressed, the

TPACK levels exhibited also progressed. With some of the participants showing individual

growth in TPACK at the end of the study, the implication is that participation in a technology-

based lesson study provided opportunities for promoting inservice teachers' TPACK. Larger-

scaled studies that involve research with ongoing lesson study and utilize multiple classroom

observations are needed to investigate this impact further.

Self-reported Data versus Classroom Observation

In gathering data to support the participants' TPACK levels, the TPACK Development

Model Self-Report Survey was instrumental in providing insight into the participants' perception

of their practices with technology. Although it was helpful to have an understanding of the

participants' perception of their practices, the data collected through this survey implied TPACK

levels that were higher than that revealed by classroom observations. The interviews provided an

opportunity to investigate further the participants' responses on the self-report survey. However,

the responses in the interviews were also self-reported. The participants tended to speak using

general statements and jargon. When asked for specific details from classroom practice to support these statements, the participants were either unable to provide such examples or the examples given were not supportive of the TPACK development levels initially implied.

The most effective data in determining TPACK development levels was from the classroom observations. Based on the findings of this research, the setting of the classroom, where practices with technology are being implemented, provides the needed context to determine teachers' TPACK development levels. Self-reported data, such as surveys, provide the teachers' perceptions of their TPACK, which are usually higher than their true TPACK levels. The implication from this study is that extended, repeated observations would better serve to determine true TPACK levels.

TPACK Development Model

With respect to the TPACK Development Model, the data gathered in this study demonstrated that a teacher's TPACK development can vary for the different themes and for different descriptors within the themes. Levels for the teaching theme, particularly, seemed to be just below levels for other themes. Additionally, some individual cases revealed evidence within two different levels for the same theme and descriptor. Not every descriptor was evidenced, however, within the limited data gathered for this study. More extensive studies with more data gathered from actual instructional practices within the classroom are needed to examine the relationships of the descriptors and themes within the model and the progression through the levels as teachers develop TPACK for a given technology.

Recommendations for Future Research

The findings from this study imply that participation in a technology-based lesson study provided opportunities for participants to practice actions from higher TPACK development levels. Following the lesson study, half of the individual participants demonstrated higher levels of TPACK development based on post-observations. All of the participants indicated a desire to continue to explore integrating technology as a tool to promote learning mathematics. Several of the participants also indicated a desire to continue working with other teachers to accomplish this goal of effective technology integration. With these promising results from only one cycle of lesson study and with the implication that classroom observations provided the needed context for determining TPACK development levels, larger-scaled research that involves ongoing lesson study cycles and implements multiple classroom observations are needed to investigate further the impact of participating in technology-based lesson study on inservice mathematics teachers' TPACK development.

The data gathered to determine the supports perceived by the participants as important to developing TPACK was limited. On the writing prompts, the participants ranked the components of the Teachers as Learners Phase very highly with regard to the impact on their beliefs about effective integration of technology. There was no indication from these writing prompts, however, of teachers' TPACK development as a result of the Teachers as Learners Phase. Further research is needed to examine the supports perceived by teachers as important to TPACK development as well as the effectiveness of those supports.

Examining the education and technology backgrounds and experiences of the participants in this small study with respect to progressions within the TPACK Development Model revealed

surprising findings. Those participants with more technology use in their educational experiences led the group in actions within realms of higher levels of TPACK, but demonstrated no changes in instructional practices and fewer individual changes in TPACK development. With extended lesson studies and multiple classroom observations, these findings might have been different. More research is needed to investigate how progression within the TPACK Development Model compares to prior technological and educational experiences.

Summary

This qualitative study examined inservice secondary mathematics teachers' TPACK development through participation in a technology-based lesson study. The findings indicated that participating in the technology-based lesson study provided opportunities for the participants to practice actions within the higher levels of the TPACK Development Model. Individual cases of TPACK development during the study varied, with half of the participants demonstrating higher levels of TPACK development in the lesson for the post-observation than in the lesson for the initial observation. The two participants who reported more experience with technology in their own learning experiences were active leaders during the lesson study, but did not demonstrate positive changes in individual TPACK development. The participants indicated that participating as learners in technology tasks, observing and analyzing technology lessons, and working collaboratively were beneficial in prompting changes within their beliefs about effective technology integration. Larger-scale research with ongoing lesson study and multiple classroom observations is needed to verify and extend the findings of this study.

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List of Appendices

Appendix A

TPACK Development Model

Mathematics Teacher TPACK Development Model: Themes X **Levels** X **Descriptors** X **Examples**

CURRICULUM & ASSESSMENT
C: Curriculum descriptor A: Assessment descriptor Ex: Mathematics Example

Recognizing

C: Acknowledges that mathematical ideas displayed with the technologies can be useful for making sense of topics addressed in the curriculum.

    Ex: Creates graphs of multiple linear functions using graphing calculators to provide a visual representation for varying slopes. Considers these visuals as making sense of the idea of slope but is unsure of how this might help students learn the basic concept.

A: Resists idea of technology use in assessment indicating that technology interferes with determining students' understanding of mathematics.

    Ex: Does not allow calculator use when assessing students' understanding of solving linear equations.

Accepting

C: Expresses desire but demonstrates difficulty in identifying topics in own curriculum for including technology as a tool for learning.

    Ex: Attends and participates in mathematics dynamic geometry system workshop to identify curricular ideas for incorporating the technologies as learning tools. Mimics the incorporation of a dynamic geometry system idea from the workshop to display measuring the sum of the angles of a triangle that upon multiple changes of the triangle suggests that the sum of the angles of any triangle is 180 degrees.

A: Acknowledges that it might be appropriate to allow technology use as part of assessment but has a limited view of its use (i.e., use of technology on a section of an exam).

    Ex: Attends and participates in a mathematics assessment professional development to consider ideas for assessing students' understanding of solving systems of linear functions using the calculator as a tool. Mimics the assessment idea to explain the use of the calculator for solving systems of linear functions by using the trace function to identify the intersection. Often retests technology questions with paper and pencil questions to be sure that the concept was learned the 'right' way.

Adapting

C: Understands some benefits of incorporating appropriate technologies as tools for teaching and learning the mathematics curriculum.

    Ex: Targets key topics students investigate with technology. Develops lessons to demonstrate mathematics concepts with technology and activities for students to use technology to verify or reinforce those concepts. After students have learned to create graphs of specific linear functions, students are challenged to use the spreadsheet to verify the graphical representation of the ordered pairs.

A: Understands that if technology is allowed during assessments that different questions/items must be posed (i.e., conceptual vs. procedural understandings).

    Ex: Allows use of calculator in an assessment but designs the assessment to focus on gathering students' conceptual understanding of solving systems of linear functions in addition to their procedural understanding.

Exploring

C: Investigates the use of topics in own curriculum for including technology as a tool for learning; seeks ideas and strategies for implementing technology in a more integral role for the development of the mathematics that students are learning.

    Ex: Adapts own previous mathematics lesson to include technology.

Ex: Develops own ideas about using technology to enhance current curriculum; thus, begins altering preexisting activities or creating new activities for current curriculum.
A: Actively investigates use of different types of technology-based assessment items and questions (e.g., technology active, inactive, neutral or passive).
  Ex: Designs assessments where students are expected to show their understanding of mathematical ideas using an appropriate technology that extends beyond paper and pencil type questions.

Advancing

C: Understands that sustained innovation in modifying own curriculum to efficiently and effectively incorporate technology as a teaching and learning tool is essential.
  Ex: Develops innovative ways to use technology to develop mathematical thinking in students such as using virtual algebra tiles to extend ideas of handheld manipulatives to focus on variables in algebraic expressions.
  Ex: Modifies and advances curriculum to take advantage of technology as a tool for teaching and learning such as using CAS to explore more complex algebraic expressions.
A: Reflects on and adapts assessment practices that examine students' conceptual understandings of the subject matter in ways that demand full use of technology.
  Ex: Develops innovative assessments to capture students' understandings of the mathematics embedded in the particular technology.

LEARNING

M: Mathematics learning descriptor   C: Conception of student thinking descriptor   Ex: Mathematics example

Recognizing

M: Views mathematics as being learned in specific ways and that technology often gets in the way of learning.
  Ex: Mathematical exploration with technology rarely seen.
C: More apt to accept the technology as a teaching tool rather than a learning tool.
  Ex: Technology is used only outside of normal classroom activities, such as checking homework, calculating large numbers, etc.

Accepting

M: Has concerns about students' attention being diverted from learning of appropriate mathematics to a focus on the technology in the activities.
  Ex: Limits student technology use, particularly during the introduction and development of key topics.
C: Is concerned that students do not develop appropriate mathematical thinking skills when the technology is used as a verification tool for exploring the mathematics.
  Ex: Activities that use technology are almost always redone without technology to be certain students really learned the particular concept.

Adapting

M: Begins to explore, experiment and practice integrating technologies as mathematics learning tools.
  Ex: Students explore some mathematics topics using technology.
C: Begins developing appropriate mathematical thinking skills when technology is used as a tool for learning.
  Ex: Although students use technology for most topics, assessing student thinking remains mostly technology free.

Exploring

M: Uses technologies as tools to facilitate the learning of specific topics in the mathematics curriculum.
  Ex: Students explore numerous topics using technology, sometimes ranging outside the topic at hand.
C: Plans, implements, and reflects on teaching and learning with concern for guiding students in understanding.
  Ex: Technology activities are implemented and evaluated with respect to student learning of mathematics and student attitudes toward mathematics.
  Ex: Manages technology-enhanced activities towards directing student engagement and self-direction in learning mathematics.

Advancing
   M: Plans, implements, and reflects on teaching and learning with concern and personal conviction for student thinking and understanding of the mathematics to be enhanced through integration of the various technologies.
      Ex: Students explore mathematics topics, integrating various technologies in attempts to better understand mathematical concepts.
   C: Technology-integration is integral (rather than in addition) to development of the mathematics students are learning.
      Ex: Engages students in high-level thinking activities (such as project-based and problem solving and decision making activities) for learning mathematics using the technology as a learning tool.
      Ex: Technology is used to develop advanced levels of understanding of mathematical concepts.

TEACHING
M: Mathematics learning descriptor I: Instructional descriptor E: Environment descriptor
PD: Professional development descriptor Ex: Mathematics example

Recognizing
   M: Concerned that the need to teach about the technology will take away time from teaching mathematics.
      Ex: Students use technology on their own and little or no instruction with technology is present.
   I: Does not use technology to develop mathematical concepts.
      Ex: Technology, if used in class, is used for menial or rote activities.
   E: Uses technology to reinforce concepts taught without technology.
      Ex: Focus on linear functions where students practice creating graphs by hand to explore different functions. After students have demonstrated competence with linear functions, summarize the knowledge, with a spreadsheet example or a graphing calculator example.
   PD: Considers attending local professional development to learn more about technologies.
      Ex: Attends local workshops that focus on gaining skills with the technology; context of the learning activities is mathematics.
Accepting
   M: Uses technology activities at the end of units, for "days off," or for activities peripheral to classroom instruction.
      Ex: Technology-enhanced activities are not used for topics that require more advanced technology skills.
   I: Merely mimics the simplest professional development mathematics curricular ideas for incorporating the technologies.
      Ex: Introduces the Pythagorean Theorem algorithmically; teacher use of dynamic geometry to verify the Pythagorean Theorem; students find solutions to example problems using paper and pencil.
   E: Tightly manages and orchestrates instruction using technology.
      Ex: Technology is directed, in a tightly sequenced, step-by-step process. Skill-based, non-exploratory technology use.
   PD: Recognizes the need to participate in technology related PD.
      Ex: Seeks out technology-related professional development, workshops that are directed at developing the technology in the learning of mathematics.
Adapting
   M: Uses technology to enhance or reinforce mathematics ideas that students have learned previously.
      Ex: Students use technology to reinforce previously teacher-taught concepts.
   I: Mimics the simplest professional development activities with the technologies but attempts to adapt lessons for his/her mathematics classes.
      Ex: Technology-based lessons are incorporated that are tailored to students' needs.
   E: Instructional strategies with technologies are primarily deductive, teacher-directed in order to maintain control of the how the activity progresses.

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Ex: Begins to adapt instructional approaches that allow students opportunities to explore with technology for part of lessons.

PD: Continues to learn and explore ideas for teaching and learning mathematics using only one type of technology (such as spreadsheets).

Ex: Shares ideas from professional development with other mathematics teachers in the building.

Exploring

M: Engages students in high-level thinking activities (such as project-based and problem solving and decision making activities) for learning mathematics using the technology as a learning tool.

Ex: Teachers share classroom-tested, technology-based lessons, ideas, and successes with peers.

I: Engages students in explorations of mathematics with technology where the teacher is in role of guide rather than director of the exploration.

Ex: Students use technology to explore new concepts as the teacher serves mostly as a guide.

E: Explores various instructional strategies (including both deductive and inductive strategies) with technologies to engage students in thinking about the mathematics.

Ex: The teacher incorporates a variety of technologies for numerous topics.

PD: Seeks out and works with others who are engaged in incorporating technology in mathematics.

Ex: Organizes teachers of similar mathematics and grade level in investigating the mathematics curriculum to integrate appropriate technologies.

Advancing

M: Active, consistent acceptance of technologies as tools for learning and teaching mathematics in ways that accurately translate mathematical concepts and processes into forms understandable by students.

Ex: Teacher is seen as a resource as novel ideas for helping students learn mathematics with technology.

I: Adapts from a breadth of instructional strategies (including both deductive and inductive strategies) with technologies to engage students in thinking about the mathematics.

Ex: The teacher helps students move fluently from one tool to another while demonstrating a focus on and a joy of deeply understanding mathematical topics.

E: Manages technology-enhanced activities in ways that maintains student engagement and self-direction in learning the mathematics.

Ex: The teacher forms and reforms learning groups where individual and group learning is valued and encouraged.

PD: Seeks ongoing PD to continue to learn to incorporate emerging technologies. Continues to learn and explore ideas for teaching and learning mathematics with multiple technologies to enhance access to mathematics.

Ex: Engages teachers in the district in evaluating and revising the mathematics curriculum to more seamlessly integrate technology throughout the grades, adjusting the curriculum for a 21st century mathematics curriculum with appropriate technologies.

ACCESS

U: Usage descriptor B: Barrier descriptor A: Availability descriptor Ex: Mathematics example

Recognizing

U: Permits students to use technology 'only' after mastering certain concepts.

Ex: Mathematical exploration with technology tools is challenged by beliefs about how students need to learn mathematics.

B: Resists consideration of changes in content taught although it becomes accessible to more students through technology.

Ex: Student access to technology is limited to 'after' they have learned the given concepts using paper and pencil procedures and only for rote activities.

A: Notices that authentic problems are more likely to involve 'unfriendly numbers' and may be more easily solved if students had calculators.

Ex: Assigns some mathematics problems using school and community data but saves then for "extra credit" work if students have calculators.

Accepting
  U: Students use technology in limited ways during regular instructional periods.
    Ex: Student activities with technology are limited to brief tightly controlled situations.
  B: Worries about access and management issues with respect to incorporating technology in the classroom.
    Ex: Students can only use technology in isolated situations or non-important learning situations.
  A: Calculators permit greater number of examples to be explored by students.
    Ex: Student use calculators to investigate patterns and functions.

Adapting
  U: Permits students to use technology in specifically designed units.
    Ex: Access to and use of technology is available for exploration of new topics, usually with the
      teacher's demonstration.
  B: Uses technology as a tool to enhance mathematics lessons in order to provide students a new way to
    approach mathematics.
    Ex: Concepts learned with technology are not assessed with technology.
  A: Concepts are taught differently since technology provides access to connections formerly out of reach.
    Ex: Students use dynamic geometry software to investigate and make connections between
      trigonometry functions.

Exploring
  U: Permits students to use technology for exploring specific mathematical topics.
    Ex: Access to and use of technology is available and encouraged for mathematics exploration during
      most class times.
  B: Recognizes challenges for teaching mathematics with technologies, but explores strategies and ideas to
    minimize the impact of those challenges.
    Ex: Technology is used extensively in assessments. Seeks out ways to obtain technology for classroom
      use and begins creating methods for technology management issues.
  A: Through the use of technology, key topics are explored, applied, and assessed incorporating multiple
    representations of the concepts and their connections.
    Ex: Simultaneous equations are developed from an authentic situation, solved, and interpreted using
      graphs, tables, symbols and data.

Advancing
  U: Permit students to use technology in every aspect of mathematics class.
    Ex: Technology is seen as an opportunity to challenge notions of what mathematics students can master.
  B: Recognizes challenges in teaching with technology and resolves the challenges through extended
    planning and preparation for maximizing the use of available resources and tools.
    Ex: Technology is used to expand the mathematics concepts that can be accessed by students.
  A: Students are taught and permitted to explore more complex mathematics topics or mathematical
    connections as part of their normal learning experience.
    Ex: Using the Internet to find interesting mathematical problems, students investigate the role that
      technologies can play in finding solutions to the problems.

Appendix B

Survey of Technology Use & Educational Background

Name_____ Courses teaching_____

Please describe your educational background by completing the table below.

	School	Date	Major & Degree	Use Technology? (Y/N)
High School				
College (Please list all)				

If you indicated that you used technology in any of your educational experiences, please describe below the technologies that were used, the purpose of the technology use, and the frequency of the technology use.

Technology Used	Purpose	How Frequently Used

Do you use technology in your classroom?_____

If yes, please indicate the technology, purpose, and frequency of use below. Use additional paper if needed.

Technology	Purpose	How Frequently Used

Please list any technology that you use in your personal life (online banking, social networking, email, iPod, etc.). Use additional paper if needed.

Technology	Purpose	How Frequently Used

Appendix C

TPACK Developmental Model Self-Report Survey

Specific to _____ (technology)

Please place a check (3) in the box to the left of each statement that describes your beliefs and/or integration of technology in your classroom. You may give additional information in the spaces provided to clarify your selections or if none of the statements describe your beliefs/integration.

	1. I can see how this technology might be useful with some of the topics in my curriculum, but I am not convinced its use will make much of a difference for my students' learning.
	2. I believe this technology would make a difference in my students' learning and would like to use this technology with my students, but I'm not really sure how to integrate its use with the topics in my curriculum.
	3. I believe this technology is beneficial to students' learning. I have allowed my students to use this technology for investigation of a few topics.
	4. I believe this technology facilitates students' learning. I have allowed my students to use this technology for investigation of several topics. I have changed some of my lessons to integrate the technology and am searching for more ways to integrate the technology into the curriculum.
	5. I am convinced that this technology is essential to promote learning for my students. My students use this technology on a regular basis. I extend the objectives in my curriculum by allowing my students the opportunities to develop deeper mathematical thinking through the technology use.
Use this space for any additional information related to the statements above.	
	6. If I allow my students to use this technology on tests, I make sure that the test questions measure what my students understand (concepts) along with what they know how to do (procedures).
	7. I design my assessments so that the students must demonstrate the understanding of the mathematics through the technology use.
	8. I allow my students to use this technology on tests. I make my tests to involve a variety of questions (some that require the technology, some that they could use the technology but it is not required, and some in which the technology use has no impact).
	9. I don't like to allow my students to use this technology on tests because I want to know what they know about mathematics, not what the technology can do.
	10. I allow my students to use this technology only on certain parts of tests or only on certain tests.

Use this space for any additional information related to the statements above.	
	11. I design my own technology lessons. When I plan my lessons, I really think about how to integrate the technology to help the students better understand the mathematics. After the lesson I reflect on the lesson and how it could be changed to increase student understanding using this and/or other technologies.
	12. I believe that if my students use this technology too often, they will not learn the mathematics for themselves.
	13. I have allowed my students to explore a few topics using this technology even before the topics are discussed in class.
	14. I am afraid that if I try to introduce a new topic with this technology, that my students will be too distracted by the technology use to really learn the mathematics. I want them to learn how to do it on paper first, and then they can use the technology.
	15. My students explore several topics for themselves using this technology to help them develop a deeper understanding. Sometimes the students' thinking guides their explorations in directions other than what I had planned.
Use this space for any additional information related to the statements above.	
	16. If my students use the technology to explore a new topic, they won't think about and develop the mathematical skills for themselves.
	17. I often use pre-made technology activities to engage my students in their learning. I reflect on my students' thinking, communication and ideas during the technology use to make decisions about any changes that need to be made in the design of the lesson.
	18. I might show my students how this technology relates to the topic, and I don't mind if my students use this technology outside of class, but I do not plan to allow class time for the students to use this technology.
	19. I try to use this technology to promote my students' thinking, but have not had a lot of success.
	20. I cannot imagine my classes without this technology! Using this technology is a vital piece of facilitating my students' learning and helps promote their thinking to more advanced levels.
Use this space for any additional information related to the statements above.	
	21. This technology might be useful, but before I could use this technology, I would have to teach my students about the technology and how it works. I have too many objectives to cover to do that.

	22. I use this technology occasionally such as between units or at the end of the term. The technology use doesn't necessarily tie with the mathematical goals of the class.
	23. I use this technology to reinforce concepts that I have taught earlier or that my students should have learned in a previous class. I do not use it regularly when teaching new topics.
	24. I use this technology as a learning tool to engage my students in high-level thinking activities (such as projects or problem-solving).
	25. I use this technology to present mathematical concepts and processes in ways that are understandable to my students. I actively accept and promote use of this technology for learning mathematics. Other teachers come to me as a resource for ideas of how to help their students use the technology to promote understanding.
Use this space for any additional information related to the statements above.	
	26. When my students explore with this technology, I serve as a guide. I do not direct their every action with the technology.
	27. I have led my students through a few simple ideas of how to use this technology that I learned during professional development.
	28. On a regular basis, I use a wide variety of instructional methods with this technology. I present tasks for my students to engage in both deductive and inductive strategies with the technology to investigate and think about mathematics to deepen their understanding.
	29. My students and I use this technology for procedural purposes only.
	30. I have led my students through uses of this technology that I learned during professional development, but I changed the activities to meet the needs of my students.
Use this space for any additional information related to the statements above.	
	31. I allow my students to use this technology to assist them with their skills. I direct my students step-by-step to use this technology.
	32. I have explored a variety of instructional methods with this technology, to allow my students to engage both inductively and deductively.
	33. I use this technology in a student-led environment, where the students explore with the technology both individually and in groups. When working in groups, all members of the group are actively involved.
	34. I use some exploration activities with this technology, but I usually guide my students through the steps to save class time.
	35. In my class, the focus is on the mathematics first. I can imagine that perhaps this technology might be used to reinforce those mathematical ideas only after the students have shown they can perform the skills on paper.

Use this space for any additional information related to the statements above.	
	36. I am likely to attend professional developments related to technology use in mathematics education and to share those ideas with other teachers in my building, but I am likely to focus on learning one type of technology integration at a time.
	37. I believe it is time to transform our mathematics curriculum to one that utilizes 21st century technologies! I have found organizations and workshops that I can attend to learn more about how to integrate this and other technologies into my mathematics curriculum. I plan to share what I learn with others in my district.
	38. I have made contact with others who are using this technology and plan to meet and work with them throughout the year to integrate this and other technologies appropriately into our mathematics curriculum.
	39. I would consider attending a workshop demonstrating the use of this technology, but only if it is local.
	40. I am interested and would be likely to attend workshops or professional developments to learn more about how to use this technology to further mathematics education.
Use this space for any additional information related to the statements above.	
	41. My students can use this technology only after they have mastered the pencil-and-paper skills.
	42. I allow my students to use this technology on a regular basis, usually just for skill purposes and under tightly controlled circumstances.
	43. I have a few units in which I allow students to explore new topics with this technology.
	44. I encourage my students to use this technology during most class meetings. They often explore new topics using this technology.
	45. I allow my students to use this technology in every aspect of the class and encourage the technology use to challenge the boundaries of what they can learn and understand.
Use this space for any additional information related to the statements above.	
	46. Using this technology presented some issues, but through extra planning and preparation, I have overcome those challenges and maximize the use of this technology resource.
	47. It takes to much time and hassle to allow the use of this technology everyday. I will let my students use it from time to time, maybe when we aren't so rushed to cover objectives.

	48. I know that using this technology presents some new management issues, but I actively look for ways to minimize those challenges so that my students can use this technology on a regular basis.
	49. Using this technology will present some management issues, but I plan to integrate this technology as a tool to enhance some, but not all, of my lessons and help my students take a new approach to learning mathematics in some units.
	50. Mathematics has not changed just because we have more technologies available. Students still need to know how to do everything they've always been taught. For example, my students can use the calculator to take square roots after they prove to me that they know how to do the algorithm to find square roots.

Use this space for any additional information related to the statements above.

	51. Using this technology allows my students access to explore and apply key concepts using multiple representations (such as symbols, graphs, tables, and/or data lists) and making important connections among representations and concepts.
	52. I see the use of this technology tool for simplifying some "messy math" problems (problems with "unfriendly" real-life numbers for example). I make this technology available on the rare occasion that we encounter those type problems (maybe for extra credit).
	53. Using this technology allows me to demonstrate more examples.
	54. My students regularly explore and apply key concepts of more complex mathematical topics than normally outlined for this class using multiple representations and connections.
	55. I take a different approach to teaching using this technology. Through its use, my students not only explore and apply key concepts using multiple representations, but they are also able to examine more complex mathematics topics making mathematical connections than they would be able to without the technology use.

Use this space for any additional information related to the statements above.

Evaluation Code for TPACK Self-Report Survey

Statements in this survey were based on the examples of the Mathematics TPACK Developmental Model (Niess, 2009). Below are the themes for each group of statements and the TPACK levels for each statement.

Curriculum Theme
1. Recognizing
2. Accepting
3. Adapting
4. Exploring
5. Advancing

Assessment Theme
6. Adapting
7. Advancing
8. Exploring
9. Recognizing
10. Accepting

Learning Theme – mathematics learning
11. Advancing
12. Recognizing
13. Adapting
14. Accepting
15. Exploring

Learning Theme – conception of student thinking
16. Accepting
17. Exploring
18. Recognizing
19. Adapting
20. Advancing

Teaching Theme – mathematics learning
21. Recognizing
22. Accepting
23. Adapting
24. Exploring
25. Advancing

Teaching Theme – instruction
26. Exploring
27. Accepting
28. Advancing
29. Recognizing
30. Adapting

Teaching Theme – environment
31. Accepting
32. Exploring
33. Advancing
34. Adapting
35. Recognizing

Teaching Theme – professional development
36. Adapting
37. Advancing
38. Exploring
39. Recognizing
40. Accepting

Access Theme – usage
41. Recognizing
42. Accepting
43. Adapting
44. Exploring
45. Advancing

Access Theme – barrier
46. Advancing
47. Accepting
48. Exploring
49. Adapting
50. Recognizing

Access Theme – availability
51. Exploring
52. Recognizing
53. Accepting
54. Advancing
55. Adapting

Appendix D

Interview Protocol

Please state your name, the grades and subjects you teach, and the school that you teach in.
During this interview, please do not refer to any student or teachers using their names. If you need to reference a student, teacher or other person, please use other identifiers. You can choose not to answer a particular question or to end this interview at any point. Do you understand that participation in this study is voluntary?
How do you feel about teaching with technology? How have these feelings changed throughout your career?
Please describe your experiences as a learner and as a teacher using instructional technologies, such as graphing calculators, TI-Navigator systems, and educational software.
Please describe the role that technology plays in your classroom. How do your students use instructional technologies to learn mathematics in your classroom?
What factors most influence your decisions to use or not use available instructional technologies?
What role does instructional technology play in your lesson planning? Will the progress of today's lesson influence tomorrow's lesson?
How do you think other teachers in your school would describe your use of instructional technologies? Why do you think that is?
Please describe any concerns you have about using instructional technologies in your classroom.
Describe any specific or general improvements you would like to occur in the implementation of instructional technologies in your classroom.
FOR POST INTERVIEW:
How would you describe your experiences through this lesson study?
What was the most challenging aspect of participating in a lesson study?
What was the most rewarding aspect of participating in a lesson study?
Thank you for your participation today. Before I leave I'd like to schedule a time to observe a technology lesson.

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Appendix E

TPACK Observation Tool

Date _____

Teacher _____ School _____

Classroom description (including demographics, seating arrangements, available technologies, etc.)

Time	General notes	Notes specific to technology and TPACK

Time	General notes	Notes specific to technology and TPACK

Theme	Indicators
Curriculum & Assessment	- Technology dependent or independent lesson - Formal or informal assessments - Alignment to framework
Learning	- Student use of technology - Awareness of student prior understandings and misunderstandings - Student engagement in Process Standards (NCTM, 2000)
Teaching	- Role of the teacher and instructional methods - Questions posed during lesson - Relating technology to mathematical goals
Access	- Technologies available and context of use - Student and teacher familiarity with technology - Access to representations

Appendix F

Writing Prompt – Professional Development

Reflect on the professional development sessions. Please check (3) the appropriate box to rate the effectiveness of each of the aspects of the professional development in shaping your ideas about the effective integration of technology in a mathematics classroom (1 – did not affect my thoughts about technology integration, 2 – little effect, 3 – some effect, 4 – great effect).

	1	2	3	4
Participating as a learner in a technology task				
Discussing pedagogical and technological issues related to the task				
Predicting students' thinking through the technology task				
Observing the technology lesson via video				
Analyzing and debriefing the technology lesson				

Please describe your thoughts/beliefs about effective integration of technology in a mathematics classroom and how they relate to the various aspects of the professional development sessions (You may use the back of this page or additional paper if needed).

Appendix G

Writing Prompt – Lesson Study

Reflect on the lesson study process. Please check (3) the appropriate box to rate the effectiveness of each of the aspects of the professional development in shaping your ideas about the effective integration of technology in a mathematics classroom (1 – did not affect my thoughts about technology integration, 2 – little effect, 3 – some effect, 4 – great effect).

	1	2	3	4
Discussing mathematical goals for lesson study				
Discussing pedagogical issues (devising good questions, predicting student responses and/or misconceptions, etc.) related to the lesson				
Discussing technological issues (when/how to use the technology, how to manage unexpected technical difficulties, etc.) related to the lesson				
Observing the first technology lesson				
Analyzing and debriefing the first technology lesson				
Revising the technology lesson plan				
Observing the second technology lesson				
Analyzing and debriefing the second technology lesson				

Please describe your thoughts/beliefs about effective integration of technology in a mathematics classrooms and how those thoughts relate to the various aspects of the lesson study process (You may use the back of this page or additional paper if needed).

Appendix H

Task Debriefing Questions

1. What are different ways your students would approach this task?

2. What misconceptions about the topic might the students have?

3. What questions would you ask your students to help clear up misconceptions or deepen understanding?

4. How does the technology serve to facilitate student understanding or engage the students in their learning?

5. Are there other ways the technology could be used to deepen understanding of the concepts?

Appendix I

Video Discussion Questions

1. What are your general thoughts about the lesson and the students' thinking?

2. Did the students seem to have any misconceptions? What questions or tasks could be used to deepen students' thinking or to clear up misconceptions?

3. How did the technology facilitate the students' engagement and/or understanding?

4. How could this lesson be revised to be more effective?

5. What should be the next steps for this group?

VITA

Julie Whitten Riales was born to Mr. and Mrs. Frank R. Whitten, Sr., in Tupelo, Mississippi, as the youngest of three children. Julie grew up in different towns across Mississippi, graduating in 1988 as valedictorian of the Grenada High School in Grenada, Mississippi. She obtained an associate's degree from Tomlinson College in Cleveland, Tennessee, before transferring to Mississippi College in Clinton, Mississippi, where she earned a bachelor's degree with a major in mathematics and a minor in secondary education in 1992.

Julie accepted her first teaching position in fall 1992 at Coldwater High School in Tate County, Mississippi, where she taught General Math II, Algebra I, Geometry, and Advanced Math. In June 1993, Julie married Kevin Cay Riales of Hernando, Mississippi. The following June, Julie gave birth to their first son, Brian Ray Riales. In 1995 Julie was selected as the STAR teacher at Coldwater High School.

After teaching at Coldwater High School for three years, Julie transferred to Grenada High School in Grenada, Mississippi, where she taught Geometry for one year before accepting a position in 1996 at Southaven High School in DeSoto County, Mississippi. At Southaven High School, Julie taught Algebra I and II. In May 1999, Julie gave birth to a second son, Dylan Cay Riales. During the 2000 – 2001 school year, she successfully completed the process to obtain certification by the National Board of Professional Teaching Standards.

After teaching at Southaven High School for six years, Julie returned to Grenada County, where she taught seventh-grade math, pre-algebra, and eighth-grade Algebra I at Grenada Middle School for four years. In the 2006 – 2007 school year, Julie transferred to Grenada High School to teach Algebra I and II.

Julie began graduate-level studies at The University of Mississippi in fall 2005, while still teaching full-time. She completed her master's degree in education with an emphasis in curriculum and instruction in August 2007. After a one-year break, Julie entered the doctoral program in education with an emphasis in curriculum and instruction as a full-time student. She was granted a fellowship through the Center for Mathematics and Science Education (CMSE), where she worked part-time, to assist in funding her studies. In recognition of academic excellence, Julie was inducted into the Phi Kappa Phi Honor Society in 2008. She continued teaching half-days at Grenada High School for the 2008 – 2009 school year, after which she took a leave from teaching at the grade 7 – 12 level to focus on completing her graduate studies. With secondary mathematics as her area of study, her course requirements included several graduate-level mathematics courses. With careful selection of these courses, Julie completed a Master of Arts degree in mathematics in May 2010 while completing coursework for her doctoral program. Julie was awarded the Lamar Memorial Scholarship in summer 2010.

In fall 2011, Julie was the instructor for the mathematics content course for senior-level secondary mathematics teacher candidates at The University of Mississippi. She worked collaboratively with the instructor of the secondary mathematics methods course to redesign the content course to complement the methods course and to model standards-based instruction. She also incorporated technology-based learning experiences in the content course.

Through the fellowship at CMSE, Julie participated in several professional experiences. She served as a research assistant on a study sponsored by the National Science Foundation, planning and providing professional development as well as individual support for participating teachers as they learned to implement the TI-Navigator system in their Algebra I classes. She

was also co-principle investigator on a research study to investigate the impact of watching a sequenced set of video cases on elementary pre-service teachers' understanding of standards-based instruction. She presented findings of these studies at conferences of state and national professional organizations. She also prepared and presented several other sessions at local, regional, state, and national conferences of professional organizations. This dissertation stemmed from her involvement in these research studies.

Just prior to completion of her doctoral program in spring 2011, Julie was selected by the faculty of the School of Education to receive the Graduate Achievement Award in Curriculum and Instruction.