CHARACTERIZING MIDDLE GRADE MATHEMATICS TEACHERS' TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK) IN PRACTICE

A Dissertation Presented to the
Faculty of the College of Education
University of Houston

In Partial Fulfillment
of the Requirements for the Degree

Doctor of Education

By

Karman Kurban

May 2016

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Abstract

Effective teaching with technology requires a developed, nuanced understanding of the complex interplays between three key kinds of knowledge: content knowledge, pedagogical knowledge, and technological knowledge; and how they play out in specific contexts (Mishra & Koehler, 2006). Mishra and Koehler’s (2006) model for describing this complexity of knowledge is called technological pedagogical and content knowledge (TPACK).

Much of the research about TPACK attends to pre-service and practicing teachers’ beliefs and attitudes about technology and about self-efficacy beliefs regarding integrating technology in practice. Additional research uses rubrics to assess TPACK but are limited in that the data sources are oftentimes only a lesson plan. The purpose of this study was to characterize teachers’ TPACK more comprehensively by attending to the planning of, the implementation of, and reflections about lessons that incorporate technology.

The data for the study came from a graduate course for middle school science and mathematics teachers about using technology in instruction. The course was taught four times over four years and included an assignment called the *Technology Lesson Cycle*. The *Technology Lesson Cycle*, a representation of how teachers operationalize their TPACK in practice, consisted of a written lesson plan, video of implementation of the lesson, and a written reflection about the lesson. The first phase of this study was the development of a rubric to characterize TPACK. Interrater reliability of the rubric was examined using Intraclass Correlation, and the internal consistency of the scores was tested using Cronback's Alpha. Once reliability and validity of the rubric was established, fifteen *Technology Lesson Cycles* were assessed.

Findings from the study illustrate that the in-service mathematics teachers' pedagogical knowledge (PK) and the knowledge components that contain PK are significantly weaker than other components. Among all seven TPACK components, the technological pedagogical knowledge (TPK) was the weakest knowledge component. This work brought forward a deeper understanding of how TPACK translates to practice. Recommendations were provided for teacher education programs and for future studies.
Keywords: Teacher Knowledge, TPACK, Technology Integration, Rubric Development, and Technology Lesson Cycle

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Chapter I

Introduction

Incorporating appropriate technologies in mathematics instruction is an expectation across national standards (National Council of Teachers of Mathematics, 2000). Research specific to technology integration suggests that teachers' understanding of appropriate uses of pedagogical methods with technology can have an impact on student learning (Lambert & Sanchez, 2007; Margerum-Leys & Marx, 2002). To have a positive impact in the classroom, mathematics teachers need to have a deep and broad understanding of the content they teach, pedagogical knowledge of how students learn, and technology knowledge of how technology supports student learning. Based on research, a framework commonly used to describe teacher knowledge as it relates to the incorporation of technology is referred to as technological pedagogical and content knowledge (TPACK) (Mishra & Koehler, 2006). Figure 1 illustrates TPACK as the intersection of the three primary forms of knowledge of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technology Knowledge (TK).

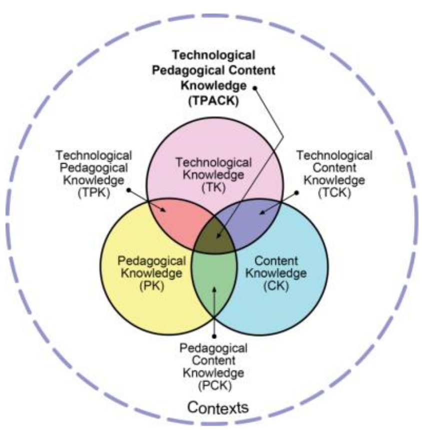

Figure. 1. Graphic representation of technological pedagogical content knowledge (TPACK), Mishra, P. & Koehler, M. J. (2006, p 1025).

A succinct definition of TPACK is as follows: (A more comprehensive definition of TPACK and its components are provided in Appendix A.)

> TPACK is the basis of effective teaching with technology, requiring an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge to develop new epistemologies or strengthen old ones. (Koehler & Mishra, 2009, p. 66)

The most important characteristic of this framework is the ways in which the areas intersect and inform one another. This allows for one to focus on teachers' technological pedagogical knowledge (TPK). It also demonstrates the ways in which the knowledge of best practices and the knowledge of technology combine so that a teacher implements technology in a way that best impacts student learning. When all three areas are combined for TPACK, it forms a framework in which teachers' knowledge is combined to produce effective teaching of content utilizing technology in a way that identifies, produces, and enhances student learning (Harris, Mishra, & Koehler, 2009; Koehler & Mishra, 2009; Koehler & Mishra, 2006).

Need for the study

There is a wealth of research related to the use of TPACK as a framework for conceptualizing teachers' knowledge as it relates to pedagogy and technology. Research focused on pre-service teachers' beliefs about technology integration has suggested that understanding pre-service teachers' knowledge, attitudes, and beliefs about educational technology provides insight only on how they are likely to use technology in a classroom (Archambault & Crippen, 2009; Doering, Scharber, & Miller, 2009; Graham et al., 2009; Harris, Mishra, & Koehler, 2009; Koehler & Mishra, 2006; Yurdakul et al., 2012). More recently, studies have focused more on how one might assess TPACK using teacher created written lesson plans (Harris, Grandgenett, & Hofer, 2010; Kereliuk, Casperson, & Akcaoglu, 2010; Kim et al., 2015). These studies have helped to conceptualize teachers' TPACK, however, they have not included the actual implementation of the lesson. In other words, research centered on the use of teaching practice data which includes multiple components to characterize teachers' TPACK has not happened.

Purpose of the study

The purpose of this study was to characterize mathematics teachers' TPACK using written lesson plans, videotaped implementation of the lesson, and teachers' reflections about the lesson. As Kahan, Cooper, and Bethea (2003) suggest, using multiple data sources to characterize teaching is desirable. To better understand the middle-grade mathematics teachers' TPACK characteristics, a new method was adopted in this researcher's study. The intent was to use a rubric to analyze lesson cycle data of fifteen middle-grade in-service mathematics teachers to learn how they use TPACK and how the study could infer TPACK from written documents and videos of instruction. Descriptive analysis, observation, and content analysis methods were used to analyze the practicing data of the mathematics teachers who were enrolled in a graduate course about using technology in instructional practices.

Research Question

The research question for this study was: “In what ways can we characterize middle school mathematics teachers’ TPACK?”

Significance of the Study

This study used multiple data sources to assess in-service middle-grade mathematics teachers’ TPACK, a procedure that has not been often used in the literature. The methodology developed in this study could potentially contribute to the literature for assessing teacher knowledge. The results of this study provided further evidence of how CK and PK, CK and TK, and PK and TK intersect in the TPACK framework described by Mishra and Koehler (2006). Characterizing in-service mathematics teachers’ TPACK in practice can potentially expand the understanding of teachers’ TPACK and how they use their TPACK in their classroom. The characterization helps teacher educators in identifying teachers’ specific TPACK (CK, PK, TK, PCK, TCK, TPK) levels, leading appropriate professional development programs for specific areas. Findings from a study such as this would also inform teacher educators in designing coursework and professional development regarding educational technology integration in teaching.

Definitions of Terms/Key for Abbreviations

In this dissertation research study, the following terms and abbreviations will be used. Following are thumbnail definitions of each of them.

TPACK: Technological pedagogical and content knowledge (see Appendix A).

CK: Content knowledge.

PK: Pedagogical knowledge.

TK: Technological knowledge.

PCK: Pedagogical knowledge.

TCK: Technological content knowledge.

TPK: Technological pedagogical knowledge.

TPACK: Technological pedagogical and content knowledge.

TPACK Components:

Individual knowledge domains including CK, PK, TK, PCK, TCK, TPK.

Technology Lesson Cycle:

This was an assignment in-service middle-grade mathematics teachers submitted during a graduate course CUIN 6346 "Teaching secondary mathematics with technology." The lesson cycle assignment was a full lesson, including a written lesson plan, videotape of implementation of the lesson, reflections about the lesson, and a brief literature review about the chosen technology of the lesson. In addition, the assignment was an archived assignment in Blackboard Learn at the university.

CUIN 6346 "Teaching Secondary Mathematics with Technology":

As a graduate course, CUIN 6346 was a part of an M.Ed. program for in-service mathematics and science teachers at the university where the study was conducted. The course had been taught during the fall semester since 2011.

TPACK characterization:

The characterization of TPACK involved using a rubric developed for this study specifically to assess a teacher's TPACK level through analysis of the teacher's practicing data and characterization of the teachers' knowledge from weak to strong (1 = Weak; 2 = Marginal; 3 = Proficient; and 4 = Strong).

The rubric (1 = Weak; 2 = Marginal; 3 = Proficient; and 4 = Strong):

Phase one of the study centered on the development of a rubric for the characterization process. The rubric was developed using construct analysis (Cox, 2008) through multiple rounds of analysis, revision, and reliability testing for characterizing in-service mathematics teachers' TPACK in practice. Discussions about rubrics in the literature provided guidelines and steps on how to create a rubric for a specific study (Mertler, 2001). Analytic rubrics are usually preferred, according to Nitko (2001), when a focused type of response is required. Also, Clement et al (2003) recommended that clearly defined constructs and a team of two to four people be used support the development of research rubrics. The process of developing the rubric in this study was guided by this literature.

TPACK characterization pattern chart:

This refers to the chart used to show the teachers' weak to strong TPACK level in establishing a pattern observation. A color coding method was used for observations to characterize the teachers' knowledge from strong to weak (Green = Strong; Blue = Proficient; Orange = Marginal; and Red = Weak)

Summary

Many studies have conceptualized teachers' TPACK by assessing teacher-created written lesson plans (Harris, Grandgenett, & Hofer, 2010; Kereliuk, Casperson, & Akcaoglu, 2010; Kim et al., 2015). However, these studies have not included the actual implementation of the lesson. The use of teaching practice data, which includes multiple components to assess teachers' TPACK, provides greater understanding of teachers' knowledge levels and how they employ TPACK in teaching. The purpose of this study was to characterize middle-grade mathematics teachers' TPACK during their classroom practice. The intent was to use the developed rubric to analyze lesson cycle data of fifteen middle-grade in-service mathematics teachers in order to assess their TPACK levels during classroom practice. This study consisted of two phases. The first phase was the development of the rubric using pilot data through multiple rounds of analysis and revision for characterizing TPACK in practice. The second phase was the application of lesson cycle assignment data of the fifteen middle-grade mathematics teachers to the rubric to determine their TPACK characterization using descriptive, video, and content analysis methods. The results were organized in the TPACK characterization pattern chart for a pattern observation and the TPACK characterization.

The literature about rubric developments, understanding the TPACK, its impact on teaching practice, and the TPACK conceptualization and characterization is reviewed explicitly in Chapter II. In Chapter III, the detailed methodologies of the study, including development of the rubric, data, participants, and the data analysis process, are described. The analysis and characterization results are presented in Chapter IV. The conclusions of the study and recommendations for next steps are discussed in Chapter V.

Chapter II

Literature Review

Many studies have been presented to understand and characterize teacher knowledge. This review focuses on three major categories of literature that inform this research. The categories include rubric development, understanding TPACK and its impact on teaching practice, and the conceptualization and characterization of TPACK.

Rubrics and Rubric Development

During the last few years, scholarship addressing the complex teachers' knowledge TPACK has focused increasingly on how this knowledge can be assessed. Several studies developed self-reported survey instruments for reliability and validity of TPACK assessment (Archambault & Crippen, 2009; Schmidt, Baran, Thompson, Koehler, Shin & Mishra, 2009). For example, Koehler, Mishra, and Yahya (2007) developed a coding protocol consistent with the TPACK framework. These studies also developed performance assessments (Angeli & Valanides, 2009; Groth, Spickler, Bergner & Bardzell, 2009). At least four studies developed valid rubrics using teachers' lesson plan data for assessing teachers' knowledge (Harris, Grandgenett & Hofer, 2010; Hofer, Grandgenett, Harris & Swan, 2011; Kereluik et al., 2010; Kim, et al., 2015). The rubric developed in this study was used to assess teachers' comprehensive lesson cycle assignment that included a lesson plan, a literature review about technology, a videotaped lesson, and teacher reflections about the lesson necessary.

Many discussions about rubrics in the literature have provided guidelines for how to create a rubric in a general sense, including types of rubrics and the advantages of using rubrics. According to Metler (2001), rubrics are rating scales, as opposed to checklists, that are used with performance assessments. They are defined as scoring guides, consisting of specific pre-established performance criteria, used in evaluating student work on performance assessments. Rubrics are typically a specific form of scoring instrument used when evaluating student performances or products resulting from a performance task. Rubrics help to break down assignments into smaller components that can each be scored. These scores can then be combined for an overall score of the performance task.

Two types of rubrics were introduced in the literature for measuring students or teachers' performance—holistic and analytic rubrics. A holistic rubric requires the teacher to score the overall process or product as a whole, without judging the component parts separately (Nitko, 2001). In an analytic rubric, the teacher scores separate, individual parts of the product or performance first, then sums the individual scores to obtain a total score (Moskal, 2000; Nitko, 2001). According to Nitko (2001), use of holistic rubrics is more appropriate when performance tasks require students to create responses where there are no definitive correct answers. The focus of a score reported using a holistic rubric is on the overall quality, proficiency, or understanding of the specific content and skills; it involves assessment on a unidimensional level (Mertler, 2001). Use of holistic rubrics can result in a somewhat quicker scoring process than use of analytic rubrics (Nitko, 2001). This is because, when using a holistic rubric, the teacher is required to read through or otherwise examine the student product or performance only once, in order to get an "overall" sense of what the student was able to accomplish (Mertler, 2001).

Analytic rubrics are usually preferred when a fairly focused type of response is required (Nitko, 2001); that is, for performance tasks in which there may be more than one acceptable response and creativity is not an essential feature of the students' responses. The use of analytic rubrics can cause the scoring process to be slower, because assessing several different skills or characteristics individually requires a teacher to examine the product several times. Therefore, both the construction and use of analytic rubrics can be time consuming (Mertler, 2001).

The rubric developed in this study was guided by literature on analytical rubrics in scoring teachers' performance method to characterize mathematics teachers' TPACK. Instead of summing the individual scores to obtain a total score, this rubric was designed to use average score of each component of the TPACK.

Clement, Chauvot, Philipp, and Ambrose (2003) suggested a methodological approach when designing task-specific research rubrics. They developed a rubric using pilot data. To determine the appropriate category for each response, they looked for degrees of evidence related to the belief in questions. They compared categories and developed descriptions for each category. The interrater reliability of the rubric that they developed reached 87.5% level. The recommendations of Clement et al for developing rubrics were used to guide the development of the rubric for this study. Their recommendations were as follows

1) Clearly define the constructs because they serve as the foundation;
2) Use a team of two to four people when developing research rubrics. Rubric development cannot be done alone. Interpretations of responses can vary widely, but one person cannot know how others will interpret responses unless

others are simultaneously examining them—at least three per team is highly recommended;

3) Decide on a particular number of categories beforehand, but do not feel constrained to use that number of categories; for example, begin with four categories: responses that provide no evidence, weak evidence, evidence, and strong evidence of the belief. Then decide on particulars for that belief;

4) Accept that when dealing with the written word, some responses will be challenging to code. They found that 5–10% could fall into one of two categories, either because of differences in interpretation of the response or because an insufficient amount of information was provided by the respondent. (Clement et al., 2003, p226)

Mertler (2001) also recommended a few quick steps for developing rubrics that influenced this study. The steps are as follows:

1) Identify the course and assignment that the rubric will be used to assess;
2) Review the intended learning goals and outcomes for that assignment;
3) Identify which characteristics of performance will matter to you in evaluating the quality or thoroughness of the piece of student work. These are called your "criteria;"
4) For each criterion, describe what you would expect to see displayed in work at three different levels of performance. You now have three descriptive points on a scale by which you can evaluate student work. When scoring, be aware that you are working with a descriptive scale and that the distance between points is not equal. (Mertler, 2001, p.)

Harris, Grandgenett, and Hofer (2010) developed, tested, and released a reliable and valid instrument to assess the quality of inexperienced teachers' TPACK by examining their detailed written lesson plans. In their 2011 study, the instrument was tested to determine if it could be used to assess TPACK evidenced in experienced teachers' planning, in the form of spoken responses to semi-structured interview questions. To evaluate both teachers' planning and teaching, they then developed and tested another TPACK-based rubric to assess observed evidence of TPACK during classroom instruction (Hofer, Grandgenett, Harris & Swan, 2011). The rubric's internal consistency in assessing TPACK as evidenced in audio interviews was examined using the Cronbach's Alpha procedure. To analyze the rubric's test-retest reliability, a percent of adjacent agreement strategy was applied again. Finally, to provide some context on the scorers' own perceptions of expertise to perform scorings adequately, the scorers assessed their expertise levels both at the time of initial scoring and when rescoring interviews. This determined if scorers' self-perceptions of technology expertise had changed from one scoring to the next. The scorers' self-assessments confirmed their perceptions of adequate expertise (Hofer, Grandgenett, Harris & Swan, 2011). Their results showed that the rubric was robust when used to analyze experienced teachers' descriptions of lessons or projects offered in response to the interview questions.

Kereluik, et al (2010) developed a rubric to access the integration of TPACK in online lesson plans that were created by leading technology companies for the purpose of meaningful technology, pedagogy and content integration. Researchers in this study aimed to further refine their rubric by applying it to publicly available lesson plans. Their original rubric was developed out of a theoretical framework developed by Mishra and

Koehler (2006). The rubric was designed to rate TPACK and its components with 1-5 scales for each of the criteria, such as “Provide clear lesson objectives” for content. Using the rubric, two researchers coded the same twelve randomly chosen lesson plans. Preliminary analysis of coding results worked to further refine their TPACK lesson plan coding rubric by prompting the addition of new categories and the removal or refinement of old categories. Additionally, analysis of the results of the lesson plan coding showed that the lesson plans provided by technology companies utilized in their study generally lacked an overall TPACK portion in the framework. At the 2015 AMTE annual conference, Kim, Smith, and McIntyre presented a similar study, sharing a rubric they used for analyzing the relationships between perspective mathematics teachers’ beliefs and their TPACK. Results of this study found that three levels of teachers’ TPACK – beginner, intermediate, and advanced—were evidenced.

The studies previously mentioned illustrated similar processes when developing rubrics for testing teachers’ knowledge. Literature further suggested that TPACK and/or assignments need to be broken down into smaller components that be scored individually. Recommendations included using short sentences or phrases to describe at least three levels of performance for each small component that needs to be scored, using multiple assessors in order to compare scores and talk about differences, and checking for validity and reliability when developing rubrics (Clement et al., 2003; Mertler, 2001). The development of the rubric in this study adopted the methodologies that were presented in the literature review. The study’s aim to investigate multiple data for characterization of teachers’ TPACK led to a specific category and criteria design during the rubric development.

Understanding TPACK and its Impact on Teaching Practice

Teaching is a highly complex activity that requires teachers to hold multiple knowledge areas. Historically, the notion of teachers' knowledge was focused on content knowledge and pedagogical knowledge only. Over the years, however, greater access to computer technologies in the home and school has encouraged teachers to develop technology knowledge as well. More recently, the area that has received greater attention is the knowledge construct related to the integration of technology in instruction.

Shulman (1986) introduced a new way of thinking about one aspect of teacher knowledge which he called pedagogical content knowledge (PCK), acknowledging in part how content knowledge and pedagogical knowledge intersect. Based on Shulman's contribution to the field, Mishra and Koehler (2006) developed a framework for thinking about teacher knowledge as it relates to using technology. They called this construct technological pedagogical and content knowledge (TPACK). It represents the complex relationship and intersection of three primary forms of knowledge: Technology Knowledge (TK), Pedagogy Knowledge (PK), and Content Knowledge (CK) (see Figure 1, p. 1).

"TPACK is a term used increasingly to describe what teachers need to know to effectively integrate technology into their teaching practices" (Schmidt, Baran, Thompson, Koehler, Mishra, Shin, 2009, p. 123; see also Koehler & Mishra, 2009). The term helps to identify the nature of knowledge required by teachers for effective technology integration in their teaching. According to research, there is a need for understanding general TPACK characteristics that may further contribute to successful technology integration in the classroom, as well as mathematics teacher education in general (Jaipal, & Figg, 2010). TPACK and its components are further described below.

Content knowledge (CK). According to Shulman (1986), content knowledge (CK) is knowledge pertaining to the subject matter that is to be learned, including knowledge of central facts, concepts, theories, and procedures within a specific discipline. Koehler and Mishra (2009) further described CK as the knowledge of explanatory frameworks that organize and connect knowledge. In mathematics content, it implies deep conceptual and procedural understanding of the material to be mastered by students.

According to Knowledge Management and Dissemination (2010), teachers' mathematics content knowledge influences their professional practice. Much research has reported that teachers' disciplinary content knowledge is related to their classroom instructional practice (Cai, 2005; Iszak, 2008; Sowder, Phillip, Armstrong, & Schappelle, 1998; Thompson & Thompson, 1996; Thompson & Thompson, 1994; Wilson, 1994). A systematic search of education research databases examined the relationship between either teachers' disciplinary mathematics content knowledge or their knowledge of student thinking about mathematics and their classroom instructional practice. The researchers found that teachers with stronger content knowledge were more likely to respond to students' mathematical ideas appropriately and to make fewer mathematical or language errors during instruction (Knowledge Management and Dissemination, 2010).

Pedagogical knowledge (PK). Pedagogical knowledge (PK) is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims (Koehler & Mishra, 2006). According to Koehler and Mishra (2006),

> This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. (p. 64)

A teacher with deep pedagogical knowledge understands how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in their classroom (Archambault & Crippen, 2009; Ball & McDiarmid, 1990; Harris, Mishra, & Koehler, 2009; Mishra, & Koehler, 2006; Niess, 2005; Shulman, 1986).

Technology knowledge (TK). Technology knowledge (TK) pertains to knowledge and skills related to operating standard technologies. Koehler and Mishra (2009) explained that it is difficult to define technology knowledge (TK) because TK is always in a state of flux. “Any definition of technology knowledge is in danger of becoming outdated by the time this text is published” (Koehler, and Mishra, 2009, p. 64). According to Koehler and Mishra, certain ways of thinking about and working with technology can apply to all technology tools and resources. In the case of digital technologies for example, knowledge of operating systems and computer hardware, and the ability to use standard sets of software tools such as word processors, spreadsheets, browsers, and educational video games, fit in the category of technology knowledge.

They further suggested that technology knowledge also include knowledge of how to install and remove peripheral devices, install and remove software programs, and create and archive documents.

Technology brings about changes in the way teachers teach and in the way students learn. With the help of technology, students can spend more of their time on developing deeper conceptual understanding and valuable critical thinking and problem-solving skills. Research showed how students' achievement is positively affected when using graphing calculators to solve mathematics problems and when curricula is designed with graphing calculators as a primary tool (Berry, Graham, & Smith, 2006; Kastberg, & Leatham, 2005). Horton, Storm, and Leonard, (2004) found that when using the graphing calculator as an aid to teach algebra, the experimental class in their study significantly outperformed the control class on the posttest. Studies of teachers' use of graphing calculators illustrated the impact professionals have on students' mathematical knowledge and calculator expertise.

Brunvand and Byrd (2011) examined how using VoiceThread can promote learning engagement and success for all students. They argued that educators can use VoiceThread in general education, self-contained, resource rooms, and inclusive settings in large group, small group, and one-on-one learning environments. These types of computer tools allow students to participate and collaborate in multiple ways and at their own pace. VoiceThread is specifically designed to promote the collaborative development of knowledge by providing students the opportunity to share their voice, quite literally, and express opinions—regardless of their ability.

Crippen and Archambault (2012) discussed the nature of scaffolded inquiry-based instruction and how it can be applied to the use of emerging technologies, such as data mashups and cloud computing, so that students not only learn STEM content, but also begin answering critical socio-scientific questions that face the modern era. Similarly, Kruz (2013) outlined various tools available to teach the concept of balance to students using virtual manipulatives. He suggested that these tools support problem-based learning in the classroom and can be used across multiple grade levels.

One of the fundamental constructs of education is using what children know to enhance their learning in the classroom (Gee, 2005; Shaffer, 2007). Technology knowledge has become a necessary skill that teachers need to develop and hold. Teachers' technology knowledge related to video games, for example, has increasingly become an impact factor in teaching because video game systems currently offer great opportunities for more advanced learning systems to be considered by teachers in designing lessons (Maldonado, N. 2012). According to studies related to technology integration, teachers have undoubtedly increased their personal and professional uses of computer technology (Ertmer & Ottenbreit-Leftwich, 2010; Project Tomorrow, 2007). In response to the Speak Up survey, seventy-five percent (75%) of participating teachers said their students were more engaged as a result of technology and demonstrated corresponding increases in student achievement. However, more than two-thirds of parents surveyed stated they were not satisfied with how well technology is integrated into core academic subjects at school (Project Tomorrow, 2007)

Pedagogical content knowledge (PCK). Shulman (1986) described PCK as "the way of representing and formulating the content being taught that make it comprehensible to others" (p. 9). This knowledge includes knowing what teaching approaches fit the content, and likewise, knowing how elements of the content can be arranged for better teaching. This knowledge is different from the knowledge of a disciplinary expert and also from general pedagogical knowledge shared by teachers across disciplines. According to Shulman (1986), PCK is concerned with the representation and formulation of concepts, pedagogical techniques, and knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge, and theories of epistemology. "It also involves knowledge of teaching strategies that incorporate appropriate conceptual representations in order to address learner difficulties and misconceptions and foster meaningful understanding" (p. 9).

Hill, Ball, and Schilling (2008) put forward a new concept of mathematics content knowledge known as knowledge of content and students or KCS. They believed that KCS is a primary element in Shulman's (1986) concept of pedagogical content knowledge (PCK). They defined KCS as content knowledge intertwined with knowledge of how students think about, know, or learn a particular content (Hill; Ball; & Schilling, 2008). In their empirical study, they found that familiarity with aspects of students' thinking, such as common student errors, was one element of teacher knowledge. They also proposed a new model related to the content knowledge domain as mathematical knowledge for teaching (MKT), which could be used to demonstrate how KCS relates to both subject matter knowledge and PCK.

Krauss et al. (2008) provided further evidence for the applicability of Shulman's (1986) teacher knowledge in empirical settings. They investigated whether content knowledge and pedagogical content knowledge can be distinguished empirically, and whether the mean level of knowledge and the degree of connectedness between the two knowledge categories depend on mathematical expertise. They found that the degree of cognitive connectedness between CK and PCK in secondary mathematics teachers was a function of the degree of mathematical expertise (Krauss et al., 2008). Working with pre-service secondary mathematics teachers, Kahan, Cooper, and Bethea (2003) investigated the relationship between content knowledge and effective mathematics teaching. They suggested that using qualitative data is desirable when characterizing teaching in terms of all facts of teachers.

Margerum-Leys and Marx (2002) discussed the application of a complete PCK model to educational technology by focusing on educational technology as the subject matter. In their series of case studies, they used focused definitions of PCK to code field notes from teacher observations and transcripts from participant interviews. Among their findings, the authors observed the exchange of knowledge of technology between student/mentor pairs. They found that mentor teachers often learned about technology from student teachers, after which the mentor teacher would incorporate this knowledge with pedagogical knowledge to inform classroom practices. The study also revealed that knowledge about technology, such as what technology was available and how to use it, was prerequisite to developing knowledge of how technology could be useful in the classroom. The study further highlighted that a complex interplay exists between pedagogical and technological knowledge, which is useful in understanding how teachers develop their ability to integrate technology into classroom practices.

Technological content knowledge (TCK). To use technology to facilitate student learning, teachers need additional knowledge and skills that build on, and intersect with, those knowledge areas that Shulman (1986) described (Ertmer and Ottenbreit-Leftwich, 2010). According to Mishra and Koehler (2006),

> Technological content knowledge (TCK) is knowledge about the manner in which technology and content are reciprocally related. Although technology constrains the kinds of representations possible, newer technologies often afford newer and more varied representations and greater flexibility in navigating across these representations. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology. (p12)

Recommendations to integrate technology in education have become a common practice in the education system (Niess, 2005). According to Niess (2005), technology can provide teachers and students with opportunities for teaching and learning in interesting, engaging, and efficient ways. In today's education, teachers, especially mathematics teachers, are responsible for integrating technologies in their particular content teaching in order to be effective in classrooms filled with a technologically-advanced, new generation of students. It is well documented that teachers need significant on-going support to do so in effective and meaningful ways.

Wong and Li (2008), Giordano (2007), and Hernandez-Ramos (2005) found in their research that the teaching experience of teachers influenced their successful use of technology in classrooms. Gorder (2008) also reported that teacher experience is significantly correlated with the actual use of technology. Kay (2007) found that pre-service teachers who preferred authentic tasks were significantly more likely to use technology to support their teaching and their students learning in the classroom. He also found that authentic tasks and collaborative strategies were significant predictors of teacher use of computers in the classroom.

The professional development approach has been used for developing in-service teachers' technological content knowledge (TCK). Providing professional development in the use of graphing calculators has been a practice that resulted in mathematics teachers' rich use of graphing calculator in teaching. Doerr and Zanger (2000) studied how the meaning of a tool was co-constructed by students and their teacher, and how students used the tool to construct mathematical meaning out of particular tasks. In this study on practice, five patterns and modes of graphing calculator tool use emerged: computational tool, transformational tool, data collection and analysis tool, visualizing tool, and checking tool. The results of this study suggested that the nature of mathematical tasks and the role, knowledge and beliefs of the teacher influence the emergence of such rich usage of the graphing calculator. They also found that the use of the calculator as a personal device could inhibit communication in a small group setting, while its use as a shared device supported mathematical learning in the whole class setting.

Guerrero, Walker, and Dugdale (2004) examined teachers' use of computers and calculators in mathematics at the middle-grade level. Their research related to teachers' technology experience, teacher and student attitudes, technology implementation trends, and effects of technology on students' skills and conceptual understanding. The study found that whereas middle-grade teachers expressed concerns regarding technology use, student attitudes were largely positive and enthusiastic. Teachers in the middle grades expressed a variety of fears and concerns about proper usage of technology during mathematics instruction. The attitudes of students toward technology use as part of their mathematical learning were far more conclusive and positive than those of teachers.

Research suggests that electronic tools to support the teaching of mathematics can be an important part of teachers' resources for promoting student learning of mathematics (Hollbeck & Fey, 2009). With the increase in technology tools available to use for math and science instruction, teachers can utilize technologies with specific purposes so that they not only increase engagement but also develop concepts (Thach & Norman, 2008). When technology is used well in mathematics, it can have positive effects on students' attitudes toward learning, confidence in their abilities to do mathematics, engagement with the subject matter, mathematical achievement and conceptual understanding (Guerrero, S; Walker, N; Dugdale, S. 2004). Providing professional development for teachers on the integration of technology helps to promote students' interest in the subject, build confidence in their ability to learn math, and can have enormous impact on student learning.

Technological pedagogical knowledge (TPK). Mishra and Koehler (2006) described technological pedagogical knowledge (TPK) as:

> Knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. This might include an understanding that a range of tools exists for a particular task, the ability to choose a tool based on its fitness, strategies for using the tool's affordances, and knowledge of pedagogical strategies and the ability to apply those strategies for use of technologies. (p. 12)

Teaching with technology requires teachers to expand their knowledge of pedagogical practices across multiple aspects of the planning, implementation, and evaluation processes (Ertmer, & Ottenbreit-Leftwich, 2010). According to the literature, integrated technology tools have long been included in online learning to support curricular and content instruction, and professional development has provided teachers with training on technology integration so that technology and technology applications are more effectively used in the classroom (Archambault & Crippen, 2009; Harris, Mishra, & Koehler, 2009; Koehler, 201; Mishra, & Koehler, 2006).

Recent research (Bauer & Kenton, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Project Tomorrow, 2008) suggests that we have not yet achieved high levels of effective technology use, either in the United States or internationally (Kozma, 2003; Mueller, Wood, Willoughby, Ross, & Specht, 2008; Smeets, 2005; Tondeur, van Braak, & Valcke, 2007a). Furthermore, if and when technology is used, it typically is not used to support the kinds of instruction believed to be most powerful for facilitating student learning (Ertmer & Ottenbreit-Leftwich, 2010)

Researchers have suggested that teachers' technological pedagogical knowledge and their perceptions toward technologies can provide students with opportunities for learning in many ways (Barnett, 2003; Ekizoglu, Tezer, & Bozer, 2010; Moore & Kearsley, 2011; Niess, van Zee, & Gillow-Wiles, 2010-11). Teachers' beliefs with regards to technology are based on whether or not they think technology can help them achieve the instructional goals they perceive to be most important (Watson, 2006). Ekizoglu, Tezer, and Bozer (2010) studied teacher candidates' attitudes on computer technologies and their real success situations on computers, finding meaningful significant positive correlation between candidates' attitudes and their use of computer technology. Barnett (2003) also found that positive teachers' attitudes towards technology contributed to the use of computer technology, leading to an increase in students' success. According to Liaw, Huang and Chen (2007), teachers' computer self-efficacy beliefs influence teachers' use of technology in teaching and learning.

Technological pedagogical and content knowledge (TPACK). Technological pedagogical and content knowledge (TPCK) is an emergent form of knowledge that goes beyond CK, PK, TK (Mishra & Koehler, 2006). According to Mishra and Koehler,

> TPACK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (p. 66)

Abbitt (2011) described TPACK as a form of professional knowledge that technologically and pedagogically adept, and curriculum-oriented teachers use when they teach (Abbitt, 2011). As Shulman (1986) and others have argued, teachers' knowledge of effective practice requires the transformation of content into pedagogical forms. Teachers' TPACK is not limited to a particular approach to teaching, learning, or even technology integration (Abbitt, 2011). Furthermore, it is important that TPACK-based professional development for teachers be flexible and inclusive enough to accommodate the full range of teaching philosophies, styles, and approaches. Harris, Mishra, and Koehler (2009) also suggested that teachers and researchers should compare the efficacy of student learning that was planned using content-based activity types, with instruction planned in more technologically-focused ways. They further urged researchers to explore and compare the efficacy of other TPACK-based professional development models, such as the learning-by-design approach that Harris, Mishra, and Koehler (2009) introduced.

According to Mishra and Koehler (2006) TPACK should be one of the critical goals of teacher training for effective educational technology integration and developing both pre-service and in-service teachers. In recent years, many studies on teacher education used the TPACK model for conceptualizing teacher knowledge and understanding how teachers' knowledge develops, as well as for understanding how teachers integrate technology and content with the appropriate pedagogy to improve their teaching practices. TPACK emphasizes the connections among technologies, curriculum content, and specific pedagogical approaches, demonstrating how teachers' understandings of technology, pedagogy, and content can interact with one another to produce effective discipline-based teaching with educational technologies (Harris, Mishra; & Koehler, 2009, p. 396).

Harris et al. (2009) described TPACK as different from knowledge of its individual component concepts and their intersections. It arises instead from multiple interactions among content, pedagogical, technological, and contextual knowledge. They also suggested that what has been overlooked in most cases is the critical role that technology can play in teaching and learning. Harris et al. further assert that TPACK encompasses the following:

- understanding and communicating representations of concepts using technologies;
- pedagogical techniques that apply technologies appropriately to teach content in differentiated ways according to students' learning needs;
- knowledge of what makes concepts difficult or easy to learn and how technology can help redress conceptual challenges;
- knowledge of students' prior content-related understanding and epistemological assumptions, along with related technological expertise or lack thereof;
- and knowledge of how technologies can be used to build on existing understanding to help students develop new epistemologies or strengthen old ones.

TPACK Conceptualization and Characterization

Considerable research has been conducted using the framework of TPACK to conceptualize and to understand teachers' knowledge required for effective teaching and technology integration. This framework for teacher knowledge described by Mishra and Koehler (2006), has been implemented in many studies to investigate and understand specific learning activities and environments (Abbitt, 2011; Archambault & Crippen, 2009; Doering, Scharber, & Miller, 2009; Graham et al., 2009; Harris, Mishra, & Koehler, 2009; Koehler & Mishra, 2006; Yurdakul et al., 2012).

Within the context of a course focused on developing online courses, Mishra and Koehler (2006) designed a quantitative survey instrument to measure preservice teachers' perceptions of time and effort, perceptions of the learning experience, and thoughts about online learning. Four times during the academic term, participants rated their level of agreement to thirty-three statements on a 7-point Likert scale and responded to two short-answer items. With regard to TPACK, specifically, one group of five items addressed the degree to which the respondent was thinking about TPACK constructs, including three items on technology, one item on pedagogy, and one item on content. The study found statistically significant changes in responses to four of the five TPACK items related to the individual respondents and all nine items regarding the group TPACK thinking and activity. They argued that, in all cases, these were positive changes, indicating a trend toward a higher level of thought and activity related to TPACK constructs as the course progressed.

Schmidt et al. (2009) designed a TPACK survey instrument for preservice teachers majoring in elementary or early childhood education which focused on the content areas (i.e., literacy, mathematics, science, social studies) that the preservice teachers would be preparing to teach. The instrument constructed contained seventy-five items for measuring preservice teachers' self-assessments of the seven TPACK domains. This instrument measured preservice teachers' self-assessments of the TPACK domains, not their attitudes toward TPACK.

Koehler, Mishra, and Yahya (2007) developed a coding protocol related to TPACK analysis and used discourse analysis to track the development of TPACK. They analyzed the conversations of teachers working in design teams, tracking the development of each of the seven categories of TPACK over the course of a semester. Their research suggested that this approach only works when applied to specific methodology particular to unique contexts.

Yurdakul et al. (2012) developed the expanded TPACK framework as TPACK-deep scale, in order to measure pre-service teachers' TPACK. They argued that the TPACK-deep scale was a valid and reliable instrument for measuring TPACK. It may allow questioning and developing of teacher training in terms of technology integration, thus allowing for the determination of teachers' TPACK levels of during the teacher training process. Abbitt (2011) asserted that knowledge and beliefs are useful in understanding the process of designing course works for professional developments, M.Ed. programs, and teacher preparation programs. The literature reviewed contained numerous suggestions on how teacher education programs can effectively influence teachers' pedagogical decisions regarding the use of technologies. Simmt (1997) urged teacher education programs to give pre-service and in-service teachers opportunities to reflect on their personal beliefs about combining technology with mathematics and teaching and learning (Simmt, 1997). Professional development can facilitate reflection by employing multiple strategies, such as participating in classroom discussions online, technology projects, etc.

Archambault and Crippen (2009) explored how the TPACK framework has practical appeal, providing an analytical structure for researching what teachers should know and be able to do, and highlighting the importance of content knowledge when incorporating the use of technology. These are important elements, as currently a greater emphasis on the use of technology is needed as it pertains to specific subject matter (Archambault & Crippen, 2009). Archambault and Crippen (2009) examined teachers' TPACK among 596 K–12 online distance educators in the United States and measured their knowledge with respect to three key domains as described by the TPACK framework: technology, pedagogy, content, and the combination of each of these areas. They found that teachers felt strongly about their ability to deal with issues related to pedagogy and content and more hesitant when it came to issues dealing with technology. This result was likely related to the activities that traditional teachers do on a daily basis, such as planning lessons, using teaching strategies to teach content, mapping content to district standards, and assessing students’ understanding of various topics, which are the emphasis of teacher education programs (Archambault & Crippen, 2009).

Abbitt (2011) provided an overview of instruments and methods, as well as a discussion of the challenges, purposes, and potential uses of these tools for TPACK-based evaluation of pre-service teacher preparation experiences. The study suggested that although gaps undoubtedly exist in the available methods and instruments, the varied approaches to measuring TPACK can be viewed as a move toward using the TPACK framework for evaluating courses, workshops, and programs that prepare pre-service teachers to learn to use technology in classroom practices. Abbitt (2011) also pointed out that when considering the application of various methods and procedures for measuring TPACK, it is important to consider that the TPACK framework can serve both as a model for the requisite knowledge of teachers for technology integration, and as a model of how innovative technology integration emerges. Using the instruments and methods currently available, it is possible to envision the ways in which the TPACK framework serves as a lens for observing the impact of teacher preparation experiences on knowledge and cognitive processes, as well as for assessing the outcomes leading toward effective and innovative teaching practices (Abbitt, 2011).

Niess (2005) also explored the development of the relationship between technology, pedagogy, and content knowledge with pre-service teachers who were preparing to become science and mathematics teachers. Her research involved five cases in which pre-service teachers completed a one-year, graduate-level preparation program for teaching science and mathematics that included a teaching internship experience, Niess found that only some of the student teachers recognized the interplay of technology and science—despite the emphasis of such throughout the program. Niess described the student teachers' decision-making process when choosing to use or not use technology for instructional purposes. Niess also presented one case in which a student teacher worked with a mentor teacher who was experienced in designing technology-enhanced instruction. The student teacher was able to consider how a particular technology would help students overcome misconceptions about the subject matter and encourage a higher level of student learning. Although this study was exploratory in nature and limited to five cases, the interplay among knowledge of pedagogy, content, and technology during the instructional planning and reflection of pre-service teachers supported the idea that the integration of technology into teaching and learning requires a unique knowledge base concerning the affordances and constraints that technology places on content and pedagogy.

Similar to Niess (2005) and other prior work, Mishra and Koehler (2006) emphasized the idea of "interplay" between technology and PCK. As the body of research based on Mishra and Koehler's adaptation of the PCK model continued to grow, the concept of technological pedagogical knowledge became known as the TPACK framework, and many subsequent research studies focused on defining distinct TPACK constructs and developing suitable tools for assessing the level of knowledge of pre service teachers in these areas (Abbitt, 2011).

Graham, Burgoyne, and Borup (2010) examined pre service teachers' planning and decision-making by presenting participants with three instructional scenarios that were randomly selected and unique to the content area and grade level that participants indicated they would be teaching. They asked participants to describe two instructional strategies that would address the content/grade-level scenario, including one instructional strategy that used technology and one strategy that did not use technology. Using data collected from 133 participants in an instructional technology course who responded to multiple scenarios throughout the semester, the researchers developed a coding scheme for the data that included the domains of TK, TPK, and TPACK.

Harris, Grandgenett, and Hofer (2010) also focused on examining student work as evidence of TPACK and sought to develop a measure by which to triangulate students' TPACK knowledge with additional measures. Harris et al. (2010) described the process and results of developing a rubric to assess TPACK using student-created lesson plans. The authors explained the reason for a focus on lesson plans by stating that the study sought to analyze teaching artifacts that demonstrated the results of teachers' decision-making, while also providing a pragmatic window into their pedagogical reasoning as reflected in teachers' instructional plans (Harris, Grandgenett, & Hofer, 2010).

Conclusion

There is a wealth of research related to the utilization of TPACK as a framework for conceptualizing teachers' knowledge as it relates to pedagogy and technology. Much of the research about TPACK attends to pre-service and practicing teachers' beliefs and attitudes about technology and about self-efficacy beliefs regarding integrating technology in practice. Research that focused on pre-service teachers' beliefs about technology integration suggested that understanding pre-service teachers' knowledge, attitudes, and beliefs about educational technology provides insight only on how teachers are likely to use technology in a classroom (Archambault & Crippen, 2009; Doering, Scharber, & Miller, 2009; Graham et al., 2009; Harris, Mishra, & Koehler, 2009; Koehler & Mishra, 2006; Yurdakul et al., 2012).

Scholarship addressing teachers' TPACK has focused increasingly on how this knowledge can be assessed. In recent years, there have been many reliable and valid TPACK assessment instruments or frameworks published, such as: self-report surveys (Archambault & Crippen, 2009; Schmidt, Baran, Thompson, Koehler, Shin & Mishra, 2009), a discourse analysis framework (Koehler, Mishra & Yahya, 2007), and two performance assessments (Angeli & Valanides, 2009; Groth, Spickler, Bergner & Bardzell, 2009). By 2015, at least ten more validated self-report survey instruments and rubrics had appeared in the literature (Burgoyne, Graham, & Sudweeks, 2010; Chuang & Ho, 2011; Figg & Jaipal, 2011; Landry, 2010; Lee & Tsai, 2010; Lux, 2010; Sahin, 2011; Yurdakul, et al., 2012), including four validated rubrics (Harris, Grandgenett, & Hofer, 2010; Hofer, Grandgenett, Harris & Swan, 2011; Kereluik et al., 2010; Kim et al., 2015) and different types of TPACK-based content analyses that had adequate levels of interrater reliability (Clement et al., 2003; Graham, Borup & Smith, 2012; Hechter & Phyfe, 2010; Koh & Divaharan, 2011; Mouza, 2011; Mouza & Wong, 2009). Researchers believe that because of the complexity of TPACK, scholarship that develops methods for TPACK measurement will probably continue (Harris, Grandgenett, & Hofer, 2010).

More recently, studies have focused more on how one might assess TPACK using teacher-created, written lesson plans (Harris, Grandgenett, & Hofer, 2010; Kereliuk, Casperson, & Akcaoglu, 2010; Kim et al., 2015). These studies helped to conceptualize teachers' TPACK but did not include the actual implementation of the lesson. In other words, using teacher practice data to characterize teachers' TPACK has not been often utilized. Some of the literature suggested that using multiple data sources to characterize teaching is desirable (Kahan; Cooper; & Bethea, 2003). There is a need for characterizing in-service mathematics teachers' TPACK in practice in order to expand the current understanding of teachers' TPACK and how teachers use their TPACK in the classroom. This need especially includes middle-grade mathematics teachers' TPACK which plays a crucial role in children's learning at this important period in their education. This study examined teachers' TPACK through data that included a lesson plan, videotaped implementation of the lesson, and teachers' reflections about the lesson. The characterization helps teacher educators identifying teachers' TPACK levels, influencing the design of appropriate professional development programs aimed at increasing teachers' knowledge and skills necessary for integrated teaching.

Chapter III

Methodology

Teachers' technological pedagogical and content knowledge (TPACK) has been a focus in teacher education for describing and improving teaching practices that incorporate technology. A considerable body of research about TPACK is focused on understanding teachers' perceptions of their technological pedagogical and content knowledge through self-report data sources such as surveys that use Likert scales. Some research goes beyond Likert scale surveys and uses written lesson plans to assess TPACK (Harris, Grandgenett, & Hofer, 2010; Kereliuk, Casperson, & Akcaoglu, 2010; Kim et al., 2015). The use of actual teaching practice data that includes the implementation of lessons with technology to characterize TPACK is infrequent.

The purpose of this study was to characterize mathematics teachers' TPACK using a robust data set that includes the lesson planning process (written lesson plans), implementation of the lesson as represented through video, and teacher reflections about the lesson. The research question for this study was: In what ways can we characterize middle-school mathematics teachers' TPACK? Characterizing teachers' TPACK in this more comprehensive way will serve to expand the understanding of teachers' TPACK, and will help teacher educators to understand how mathematics teachers develop TPACK. In turn, this will potentially inform the design of professional development aimed at promoting the development of teachers' TPACK.

This chapter first describes the context for the study. This is followed by a discussion of the methods of data collection and development of the rubric implemented in the study. The chapter ends with an explanations of the data analysis.

Context

The participants of this study were middle-grade mathematics teachers enrolled in an online graduate course, “Teaching Secondary Mathematics with Technology,” which was a part of a M.Ed. program for in-service mathematics and science teachers at an urban university located in a south-central region of the United States. The course was designed to promote teachers’ development of various TPACK components and was taught for four fall semesters over four years. This study used archival data from fall 2012, 2013 and 2014 semesters. The researcher was a teaching assistant in the course for fall 2013. By 2013, the course content and the *Technology Lesson Cycle* assignment had stabilized. Twenty-one teachers enrolled in fall 2012, twenty-three teachers enrolled in fall 2013, and thirty-one teachers enrolled in the same course in fall 2014. Nine teachers of the fall 2012 group were mathematics teachers, ten teachers of the fall 2013 group were mathematics teachers, and fifteen teachers of the fall 2014 group were mathematics teachers.

A key assignment of this course was called the *Technology Lesson Cycle*. This assignment required the submission of a detailed, written lesson plan with multiple components. These included an evaluation plan, a brief paper describing research/literature about how the chosen technology supports student learning, evidence of learning outcomes provided by teachers, at least 20 minutes of video-taped instruction of the lesson, and teachers’ reflections about the overall lesson. Teachers chose topics and technologies that were available to them at their respective schools and were encouraged to try technologies with which they were unfamiliar. (For more information on the Technology Lesson Cycle assignment, see Appendix B.)

Data

The *Technology Lesson Cycle* assignment was archived data in Blackboard Learn, the course management system for the course. Teachers submitted the lesson plan, the literature review, and lesson reflections in a Word document. Video was submitted through a hyperlink or mailed to the instructor on a CD or USB stick. At the time of the study, some of the videos of practice were unavailable. For the purpose of this study, only complete Lesson Cycle submissions of mathematics teachers were used for analysis. Fifteen of the thirty-four mathematics teachers' Lesson Cycle submissions were complete and therefore utilized for the purposes of this study.

Rubric Development

A significant part of the methodology in this study was the development of a rubric that was used as a tool to characterize TPACK. Most of the available rubrics in the literature were designed to evaluate a specific task or an assessment, specific to the researchers' study, and therefore were not applicable to this study.

Four mathematics teachers' (all female, three middle school math, one 9^{th} grade algebra) Lesson Cycle submissions from fall 2013 were selected and analyzed as a pilot study to begin the development of the rubric. One teacher's submission was selected because the researcher, as a teaching assistant, observed that she was highly engaged in the course throughout the semester. It was hypothesized that her submission would be rich and robust in informing the rubric development. The other three submissions were randomly selected from the fall 2013 mathematics teachers' submissions.

Many discussions about rubrics in the literature provided guidelines on how to create a rubric in a general sense. This included types of rubrics and the advantages of using rubrics. According to the literature, there are two main types of rubrics: holistic and analytic. A holistic rubric requires the teacher to score the overall process or product as a whole, without judging the component parts separately (Nitko, 2001). In the analytic rubric, the teacher scores separate, individual parts of the product or performance first, then sums the individual scores to obtain a total score (Moskal, 2000; Nitko, 2001). The rubric developed in this study was guided by research on analytic rubrics, particularly in scoring teachers' performance method in order to characterize mathematics teachers' TPACK. Instead of summing the individual scores to obtain a total score, however, the rubric developed by this researcher used the average score of each component of the TPACK. An analytic rubric made sense in this study because the researcher wanted to capture the different components of TPACK, as well as the criteria that might describe teachers' knowledge of each component.

The initial rubric was constructed based on the theoretical framework developed by Mishra and Koehler (2006) through construct analysis (Cox, 2008). It was also informed by a measurement framework rubric shared by Kim, Smith, & McIntyre at the 2015 AMTE annual conference which was used for analyzing the relationships between pre-service mathematics teachers' beliefs and their TPACK. Typically, three to five different levels are used for criteria of a rubric (Allen, 2004). For the purpose of generating scoring results as precisely as possible, five levels (1-5) representing from weak to strong were chosen for the scoring criterion for the initial rubric.

Clement, Chauvot, Philipp, and Ambrose (2003) recommend the use of a team of two to four people when developing research rubrics. For this reason, three doctoral students and two faculty members were recruited to assist in informing the development of the rubric. All had been practicing K-12 science or mathematics teachers at some point in their careers. Two doctoral students were in mathematics education, while one was in science education. One faculty member was in mathematics education and one faculty member was in science education. All reviewers were familiar with the TPACK model.

For the first round of revisions, the reviewers were given one submission—the researcher's perceived strongest submission. This particular teacher's data was purposefully selected for the first-round analysis because she had the highest TPACK rating among the four teachers during the initial analysis by the researcher. The rationale was to provide an example that would give the examiners a sense of what a possible model teacher's TPACK would look like and contained sufficient information to enable examiners to provide comprehensive feedback. The reviewers were instructed to take notes regarding the clarity and utility of the rubric, and to provide recommendations accordingly. The researcher met with reviewers and incorporated revisions based on the reviewers' recommendations. Reviewers were then asked to code another teacher's data for a second round of rubric examination and feedback.

The initial rubric (see Appendix C) included four columns that indicated different components of TPACK:

1) the criteria that need to be scored;
2) the scales of 1-5 that represent weak to strong;
3) examples of evidence that lead to the rating;
4) the TPACK level of the final rating.

At the first round of analysis, the faculty and doctoral students were given the criteria for each component of the TPACK in the second column, and were asked to score with a 1 to

5 rating scale in the third column. Based on the given criteria to the specific TPAK component, the five possible ratings represented: 1 = Weak, 2 = Low-Medium, 3 = Medium, 4 = High-Medium, and 5 = Strong. The fourth column provided a space for the reviewer to give examples from the data that led to the rating. After the reviewers scored all components of the TPACK, reviewers were then asked to provide an overall rating to the teacher's TPACK based on their chosen score for each component. The following scale was used: Weak; Low-Medium; Medium; Medium-High; and Strong.

Two major concerns from reviewers that emerged after the first round of implementing the rubric were redundancy of the criteria and unclear distinctions between different levels. After considering reviewer suggestions, changes in the rubric were made to condense the criteria descriptors into a language that best represented the meanings of the components.

The three doctoral students were then asked to rate another mathematics teacher's submission for a second round of rubric examination, using the revised rubric. Two out of three examiners' analysis came back with some degrees of inconsistency. In response to the notes and discussions with the reviewers, the researcher returned to all four teachers' submissions to again garner information which was then used to refine descriptors for the different levels of criteria. Developing appropriate descriptors was particularly important considering that research (Stevens & Levi, 2005) suggests that numbers are less reliable than descriptors. For this researcher, the challenge was to make each of the five levels distinct.

The literature also suggested that the more levels designated in a rubric, the more difficult it becomes to differentiate between them and to articulate precisely why a response falls into one level and not the other (Allen, 2004). Clement, Chauvot, Philipp, and Ambrose (2003) recommended four levels when deciding on the number of levels in a rubric. Considering the difficulties in writing distinct descriptors for five levels in the initial rubric, the rating categories for the rubric were changed to four levels in order to make the rubric more practical and to increase the feasibility of its use. The four levels were: Weak, Marginal, Proficient, and Strong. As an example, one TPACK component (content knowledge) with its related descriptors for each level is shown in Figure 2. The final version of the rubric with full descriptions is provided in Appendix D.

TPACK Components	**Criteria**	**Category (1 weak – 4 strong)**					**Overall Rating (circle one)**
		1	**2**	**3**	**4**	**Score**	
Content Knowledge (CK)	A) Procedural understanding of content	Apply procedures poorly, or inefficiently;	Ability to apply procedures somewhat accurately and efficiently,	Proficient in applying procedures accurately and efficiently; transfer procedures to different problems and contexts	Strong ability to apply procedures accurately, efficiently, and flexibly; transfer procedures to different problems and contexts		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 - 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Conceptual understanding of content	Lack of ability to understand concepts being taught and encounter difficulties when use them to solve problems	Understanding concepts being taught and able to use them to solve problems with difficulty	Understanding concepts being taught and able to use them strategically to solve problems	Strong understanding of concepts being taught and able use them strategically to solve problems; strong ability to identify misconceptions		
	C)Mathematical languages	Minimum or no mathematical language	Appropriate use of mathematical language	Sufficient mathematical language and use them appropriately and frequently	Strong mathematical language ability and use the language strategically and frequently		

Figure. 2. Content Knowledge (CK) rubric.

Rubric reliability results. To test the reliability of the finalized rubric, six doctoral students in mathematics education were asked to participate using the rubric to review the same Lesson Cycle submission that was used during the first round of the rubric testing. All of the second round reviewers had taught or were teaching mathematics in public schools.

The twenty-one criteria of the TPACK in the rubric were scored by the reviewers and the average scores for each component of the TPACK, which included three criteria, were calculated. A total of seven scores from each reviewer were generated and inputted into SPSS software for statistical analysis. Interrater reliability was examined using Intraclass Correlation (0.734), and internal consistency within the rubric was computed using Cronbach's Alpha. The test result was significant ($p = 0.007$, $p < 0.05$). The results of the analysis as shown in Table 1 and 2 indicated the rubric was a valued instrument for this study. Although the results did not reach optimum 80% which was recommended by Clement et al. (2003) and by Harris, Grandgenett, and Hofer (2010), it demonstrated an internal consistency of 73.4% which is above the adequate level of 70%, according to Donner and Wells (1986).

Table 1: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.734	.713	6

Table 2: Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.315[a]	.049	.750	3.757	6	30	.007
Average Measures	.734	.237	.947	3.757	6	30	.007

Further Analysis: Identifying Patterns

Fifteen mathematics teachers' *Technology Lesson Cycle* submissions were applied to the rubric for analysis for characterizing their TPACK. Descriptive, observation, video and content analysis methods were used to analyze the mathematics teachers' complex data during the process. Lesson plans provided the general sequence of the lessons, including the lesson objective, technologies to be used, engagements and students' activities, and evaluation plans. The technology research papers provided evidence of what the teachers knew about technologies that impact classroom teaching and the rationale of why they chose the particular technologies included in the lesson. The video data was used to capture lesson content and classroom events, and to determine if the teachers' plans were implemented in the actual instruction. Teacher reflections about their lessons provided evidence of teachers' abilities to learn to adapt to new technologies and to show the ways in which teachers' understandings of the content can be changed by the application of technologies. TPACK components were characterized into the scales of 1 through 4. Based on the scores of three criteria (see Figure 2), each component of the TPACK was rated as follows:

- If three criteria were scaled weak, or if two were weak and one marginal, or if the average score was between 1 - 1.5, the particular component of a teachers' TPACK as "weak."
- If three criteria were scaled one weak and two marginal, all three marginal, or two marginal and one proficient, or the average score was between 1.5 – 2.5, the TPACK was characterized as "marginal."
- If three criteria were scaled one marginal and two proficient, three proficient, or two proficient and one strong, or if the average score was between 2.5 – 3.5, then the TPACK component was characterized as "proficient."

- If the three criteria were scaled one proficient and two strong or 3 strong, or if the average score was between 3.5 – 4, the component was characterized as “strong.”

Teachers’ TPACK results were then organized in a TPACK characterization pattern chart (Figure 3) to determine if any patterns emerged across the components. Additional recommendations were then made based on these patterns.

	Technological Pedagogical and Content Knowledge						
Teacher	CK	PK	TK	TCK	PCK	TPK	TPACK
#1							
#2							
#3							
#4							
#5							
#6							
#7							
#8							
#9							
#10							
#11							
#12							
#13							
#14							
#15							

Figure 3. In-service mathematics teachers’ TPACK characterization patterns

Limitations

In order to fully evaluate the relevance and impact of this study’s findings, the limitations of the study were fully explored in regards to data, impact, and design. The first point considered regarding data was that the participants were a unique group of teachers enrolled in an online graduate course for a M.Ed. degree at the university. Due to the fact that the data was used for a course grade (which could have contained potential sources of bias and exaggeration), the data may not have reflected the teachers’ true ability or TPACK level. Another limitation was the use of archival data in regards to teacher interviews in that it prohibited this researcher’s ability to conduct direct interviews with teachers which may have yielded a deeper understanding of their experiences in designing and implementing technology-integrated mathematics lessons.

There was also a possible impact limitation since all teachers in this study were middle-grade teachers. For this reason, the results may not be applicable to in-service mathematics teachers across all grade levels from elementary to senior high school. Finally, although the rubric developed for this study reached an adequate level of the interrater reliability, it did not reach the optimum level that is recommended in the literature which may have affected accurate data analysis.

Chapter IV

Results

The fifteen middle-grade mathematics teachers' Technology Lesson Cycle data, which represents how teachers operationalize their TPACK in practice, was applied to the rubric using descriptive and video analysis methods. The results were organized in a TPACK characterization pattern chart as shown in Figure 4. The percentages of each scale character—from weak to strong—for all teachers combined are listed in Figure 5.

Teachers	Technological Pedagogical and Content Knowledge						
	CK	PK	TK	TCK	PCK	TPK	TPACK
#1 RS4	Strong	Proficient	Strong	Strong	Marginal	Marginal	Marginal
#2 EW4	Strong	Strong	Strong	Strong	Strong	Strong	Strong
#3 EB4	Strong	Proficient	Strong	Strong	Proficient	Proficient	Proficient
#4 TG2	Strong	Strong	Strong	Proficient	Proficient	Strong	Proficient
#5 CS2	Strong	Proficient	Proficient	Strong	Proficient	Marginal	Marginal
#6 SB2	Strong	Strong	Strong	Strong	Strong	Proficient	Strong
#7 AK2	Strong	Strong	Strong	Strong	Strong	Strong	Strong
#8 AA2	Strong	Strong	Strong	Strong	Strong	Strong	Strong
#9 PG 3	Strong	Proficient	Strong	Strong	Proficient	Proficient	Proficient
#10 MB4	Strong	Proficient	Strong	Proficient	Strong	Marginal	Proficient
#11 AB4	Strong	Strong	Strong	Strong	Strong	Proficient	Strong
#12 KT3	Strong	Strong	Strong	Strong	Strong	Strong	Strong
#13 MM3	Strong	Proficient	Strong	Strong	Proficient	Marginal	Proficient
#14 TT3	Strong	Strong	Strong	Proficient	Strong	Proficient	Proficient
#15 CB4	Strong	Strong	Strong	Strong	Strong	Strong	Strong

Figure 4. In-service mathematics teachers' TPACK characterization patterns.

TPACK Scale	Technological Pedagogical and Content Knowledge						
	CK	PK	TK	TCK	PCK	TPK	TPACK
Weak	0%	0%	0%	0%	0%	0%	0%
Marginal	0%	0%	0%	0%	7%	27%	13%
Proficient	0%	40%	7%	20%	33%	33%	40%
Strong	100%	60%	93%	80%	60%	40%	47%

Figure 5. The percentage of scale character of the TPACK.

The results were based on the analysis of each of the fifteen mathematics teachers' data that consisted of written lesson plans, technology research papers, video of lesson implementation, and teachers' written reflections about the lessons. Lesson plans provided information including instructional objectives, technologies used, engagement and students' activities, and evaluation plans. The technology research papers provided evidence of what teachers knew about technologies that impact classroom teaching and the rationale for choosing particular technologies in their lessons. Video lessons provided rich evidence for characterizing teachers' TPACK. The video data was used to capture lesson content and classroom events, and served to determine if teachers' plans were implemented in the actual lessons. Teachers' reflections about their lessons provided evidence of teachers' abilities to learn and adapt new technologies, and documented their how their understanding content instruction changed via the application of technologies.

Characterization Results

Based on the data analysis, all teachers demonstrated strong content knowledge (CK). The data indicated that teachers had the ability to apply procedures accurately, efficiently, and flexibly. They also showed strong understanding of concepts being taught and were able to use them strategically to solve problems. All teachers exhibited proficient mathematical language ability, using it strategically and frequently. Most of their lesson plans were carefully planned and included detailed information about engagement and activities, the content objectives, and the technologies used. In addition, most of their lesson plans were consistent with the implementation of their lessons. Figure 6 represents a common format of the 5-E model lesson plan that was used by most teachers.

Engage the Learner

Teacher	Students
1. Activate prior knowledge by asking students to discuss the meanings of equivalent and expression 2. Randomly call students to share their expressions with the class. Continue to emphasize when expressions are equivalent.	1. Use numbers and symbols to show 36 as a sum, difference, product, and quotient. 2. When students finish creating expressions, they will compare their expressions with their groups.

Explore the Concept

Teacher	Students
1. As students find the squares of numbers up to 10, assist with creating equivalent expressions using exponents. For example: $4x4=4^2$	1. Use the area of a square to explore what exponents are. Students will find the square of numbers up to 10.

Explain the Concept and Define the Terms

Teacher	Students
1. After students finish creating the table with powers of 2, decide as a class what to add in their notebooks about exponents. (Guide students to describe exponents as a way to show repeated multiplication) 2. Show students a few exponent problems where the answer is wrong, in their groups, ask them to explain what the student did wrong. 3. Prime factorization is a topic students covered in the previous grade. Remind them of what it is. As they create prime factorizations, ask them if there is a way to write an equivalent expression using exponents. a. $8=2x2x2=2^3$ b. $20=5x2x2=2^2$	Exponents 1. Watch a video explaining exponents on the online textbook. 2. Fill in an interactive online table that shows powers of 2. Prime Factorization 1. Use the online textbook practice factoring a number into its prime factors. 2. Use the National Library of Virtual Manipulatives to practice finding the prime factorizations At the end of class, complete an exit ticket showing the prime factorization of 51, 32, and 96.

Elaborate on the Concept Students will apply their knowledge from equivalent expression and operations to create equivalent operations using order of operations and the distributive property.

Teacher	Students
1. As students write their expressions for the area, have them share with the class. Demonstrate how the common factor, h (for the unknown height) can be factored out of the expression and the expression can be rewritten using the distributive property.	1. View the Launch on the online textbook on distributive property. In groups, use the picture to write an expression for the area a rectangle broken into three piece with known lengths and unknown heights. 2. Use the interactive online textbook to find expressions that are equivalent using the distributive property. 3. Use the interactive online textbook to find expression with variables that are equivalent using the distributive property.

Evaluate Students' Understanding of the Concept

Teacher	Students
1. As students complete their expressions equal to 48, have them come to a place in the room and write their expressions. 2. After students watch the video, provide them with notes on the order of operations.	1. Use the online textbook to create two expressions that equal 48. One that uses addition and multiplication and one that uses subtraction and multiplication. 2. Watch the video about order of operations. 3. Use the interactive textbook to solve problems using the order of operations. 4. Write problems using the order of operations and give to another groups to solve. 5. Evaluate order of operations expressions. 6. Look at order of operations expressions that have been solved but with errors. Determine what the error the student who solved the problem did and correct it.

Figure 6. 5-E model lesson plan with teacher and student activities (drawn from RS4).

Sixty percent (60%) of teachers were characterized as strong in pedagogical knowledge (PK) and 40% were characterized as proficient. Ninety-three percent (93%) were strong and 7% were proficient in technology knowledge (TK). Eighty percent

(80%) were strong and 20% were proficient in technological content knowledge (TCK). In regards to pedagogical content knowledge (PCK), sixty percent (60%) were characterized as strong, 33% were characterized as proficient, and 7% were characterized as marginal. For technological pedagogical knowledge (TPK), forty percent (40%) were strong, 33% were proficient, and 27% were marginal. Finally, in the area of technological pedagogical and content knowledge (TPACK), 47% of teachers were characterized as strong, 40% were as proficient, and 13% were as marginal.

Analysis of the Lesson Cycle for the Fifteen Mathematics Teachers

For the purposes of the study and to promote anonymity, each teacher was assigned a nickname (i.e., RS4, CW4, etc.). Data from each of the fifteen mathematics teachers was applied to the rubric, the analysis of which is summarized by teacher in the following paragraphs.

RS4. RS4 was a 6th grade mathematics teacher whose lesson was about exponents, order of operations, prime factorization, and distributive properties. Entitled “Equivalent Expressions,” the lesson utilized an online textbook. The lesson plan consisted of a list of state standards, content, key vocabulary, and student misconceptions. Teaching strategies included a list of engaging activities, methods of exploring concepts, a list of activities which explained the concept and defined terms, elaborations on the concept, and evaluation of students’ understanding of the concept. There were three main topics that the teacher (RS4) planned in order to help the students create equivalent expressions: exponents, prime factorization, and order of operations. She used online assignments to determine whether students mastered a topic or needed small group intervention. To assess the lesson at the end, she had students analyze errors in incorrectly solved order of operations problems.

RS4 integrated the Online Text Book technology in her lesson for interactive learning. She included a visual snapshot of the technology she used in her lesson review. Also, she had done research on technology integration and had written two pages of a relevant literature review about interactive learning. In her research, she reported on the literature about how student achievement was affected when digital curriculums were implemented in a mathematics class.

The 24 minute lesson was a whole group activity in which students matched equivalent expressions using the distributive property. With two computers for each group of four, students worked on online activities in small groups while RS4 walked around to help students. The volume of the video was low, and the class was somewhat noisy throughout the lesson. Some students were having a difficult time logging into the online textbook at the beginning and the teacher walked around to help those students having hard time logging in. Calling on one student to share the expression that he created, the teacher emphasized when expressions were equivalent. The teacher used the clap hands strategy four times throughout the lesson to get students' attention. There were two students near the camera who were off task, talking and playing throughout the lesson. Despite the teacher making eye contact and standing next to them a few times, they continued their play after she left. There was no further disciplinary action taken.

After the lesson, the teacher (RS4) stated in her video lesson reflection that the lesson was successful despite the technology that the students used. She really liked the idea of having a textbook that students could access online, particularly one with interactive activities for students to complete. However, she thought that she could find activities covering the same concepts in other online sites which could keep students' attention better and give them more practice. The teacher stated that she should have first guided them to the resources that are available on the online textbook. This would get students in the habit of using those resources, especially if they log in at home. This was the teacher's opinion on the technology and the math content:

> *The technology is supporting or hindering the learning in this case. There are ways that the technology could have helped students more. It just is not helping students access and understand math any better than not using the technology would. I do not feel like the online textbook has activities that allowed students to build on prior knowledge. Math in Texas is difficult this year because there are a lot of gaps that students have because of all the new TEKS (Texas Assessment of Knowledge and Skills). However, even with gaps, there are still ways that instruction can bridge the gap between what students know and where they are trying to get. The online textbook does not have a way to account for these gaps. I know that all math teachers are in a unique situation where we are essentially teaching 2 years of math in 1 year so we have to supplement all of our lessons with background knowledge the students are supposed to have.*

RS4 demonstrated strong procedural and conceptual understanding of the mathematics content in the lesson plan and in the video lesson that also indicated her strong use of mathematics language. Although the teacher's classroom management of student behavior was low according to the video, her assessment was appropriate and her class activities reflected an understanding of developmental theory of learning which led to the proficient rating in her pedagogical knowledge. The video supported the teacher's strong knowledge of technology applications. In terms of her technological content knowledge, she understood the linkage between technology (Online Text Book) and content, the representation of concepts using technology, and understood that content can be changed by technology application. This evidence indicated that she had strong technological content knowledge. RS4 noted in her lesson that she was aware of possible student misconceptions, but she did not demonstrate the knowledge of teaching strategies that incorporate appropriate conceptual representations of the content in order to guide student thinking and learning, and to address learner difficulties and misconceptions. Based on this evidence, she had marginal pedagogical content knowledge.

In the video, some students were not able to use the technology to explore the content and achieve the learning goals due to classroom management issues. The teacher's pedagogical strategies and the ability to apply those strategies for use with technology was lacking. She had a marginal evaluation for her technological pedagogical knowledge. Overall, the teacher used appropriate technology to enhance content objectives and instructional strategies. She demonstrated knowledge of how to teach concepts in different ways and using technologies to help students understand problems that they face. However, her pedagogical techniques using technologies in constructive ways to teach the content. RS4 was rated as marginal for her overall technological pedagogical and content knowledge (TPACK).

EW4. EW4 was a 7th grade Pre-AP algebra teacher. The teacher planned a lesson on Line of Best Fit with Gapminder.org, a software in which students collected data to plot scatterplots and determine correlation. After determining what makes data have a positive correlation, negative correlation, or no correlation, students explored real world trend relationships on gapminder.org to identify different correlations in the data. The teacher had a full lesson plan that consisted of state standards, math content, common misconceptions, materials/technology, detailed methods of engagement, data collection and graphing to determine function relationships, activities with technologies, and an evaluation plan.

In her research, the teacher found the U.S. Census data to be a rich source for teaching algebra in context while investigating social implications of data. By tabulating the past U.S. Census data, a line of best fit can be generated with the graphing calculator to predict future population change in the United States. EW4 cited relevant references to support her rationale for the technology integration in her lesson.

In the video lesson, the teacher (EW4) used Gapminder.com to display data for students to see where other countries fell on the graph and what relationships could be examined with the program. Students were engaged while using the technology to discover the correlation between independent variables and dependent variables. EW4 used Geometer's Sketchpad to demonstrate the process graphically so that students could see the correlation.

In her lesson analysis, EW4 broke down the video lesson minute by minute to review and discuss the detailed evidence that objectives were mastered. The teacher's use of Gapminder gave real world context while allowing students to explore data relationships and trends and analyze them algebraically. Overall the lesson was enhanced by the technology for learning the objectives.

The teacher demonstrated strong procedural and conceptual understanding of the mathematics content in the lesson plan. The implementation of the lesson indicated her strong use of the mathematics language. Likewise, her content knowledge was strong. EW4's assessment was appropriate and her class activities reflected an understanding of developmental theory of learning which indicated a strong pedagogical knowledge. The teacher demonstrated also strong knowledge of understanding and operating technology application in the video which indicates her strong technology knowledge. She showed an understanding of the linkage between technology (Sketchpad and Gapminder) and content, representation of concept using technologies, and an understanding of content can be changed by the technology application. Her technological content knowledge was strong.

The teacher demonstrated knowledge of teaching strategies that incorporate appropriate conceptual representations of the content in order to guide student thinking and learning, and an understanding student misconceptions that indicated her strong pedagogical content knowledge. EW4's pedagogical strategies and ability to apply those strategies for use of the technology was also strong. She was able to guide students to use technology to explore contents and objectives. In addition, she exhibited strong technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technology to enhance content objectives and instructional strategies. She demonstrated knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

EB4. EB4 was a 6th grade mathematics teacher. Her lesson, entitles "Flipping for Fractions," utilized Dell tablets to create a blabberize.com animation. Students created a flip book that incorporated depth and complexity icons to extend their understanding of fraction concepts. The lesson consisted of objectives, TEKS, and tasks and activities that students and the teacher would engage in.

Throughout the lesson, including the planning and implementation, EB4 indicated strong understanding of procedural and conceptual understanding of the content knowledge. The teacher used rules and routines to ensure that students were actively involved in learning and there no student misbehavior occurred. Her class activities reflected an understanding of developmental theory of learning and how students learn. This evidence indicated that EB4 had proficient pedagogical knowledge. The teacher demonstrated knowledge of understanding and operating technology application in the video which indicated that she had strong technology knowledge.

She also had strong understanding of the linkage between technology and the content, representation of concept using technologies, and an understanding of the content can be changed by the technology application which indicated that she has strong technological content knowledge. There was no prominent evidence that indicated the teacher had an awareness of possible student misconceptions, understood how content elements can be arranged for better teaching, or knowledge of teaching strategies that incorporate appropriate conceptual representations of content to guide student thinking and learning. This was a comment the teacher made about the technology:

> *Unfortunately, this lesson was not successful in terms of using the technology to support timely learning… I think if our technology was better supported (network*

and hardware) this lesson could have been powerful in accomplishing my desired goals. I am not sure how reliable these resources will be in the future which makes me hesitant to say I will re-use this program going forward.

EB4 showed proficient pedagogical and content knowledge. There was no compelling evidence to indicate the teacher's pedagogical strategies and the ability to apply those strategies for use of technologies was strong. She was, however, able to guide students to use the technology to explore the content and objectives. For these reasons, she was rated as proficient in technological pedagogical knowledge. Overall, the teacher's TPACK was proficient. She used appropriate technology to enhance the content objectives and instructional strategies. Additionally, she showed the knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

In the lesson as a whole, EB4 was successful at getting students to think creatively and deeply about fraction concepts, although she encountered some technology issues during the implementation of the lesson. She discussed these issues in her review. When teachers in her school district encountered technology problems, they had to submit a technology request through Aware, an internet program, which then trickled down through the correct administrative network before someone would come to the school to troubleshoot your problem.

TG2. TG2 was a high school geometry teacher. This teacher planned a lesson on furniture design using Gateway to Technology which included a detailed introduction, equipment, procedure, evaluation plan, and standards. After researching, sketching, and brainstorming, students used 3-D CAD (computer assisted design) software to create their own design.

Throughout the lesson, including planning and implementation, the teacher (TG2) indicated strong procedural and conceptual understandings of the content knowledge. The teacher ensured that students were actively involved in learning, and there were no student misbehavior observed during the lesson. His class activities reflected an understanding of developmental theory of learning and how students learn, indicating he held strong pedagogical knowledge. The lesson video revealed knowledge of understanding and operating technology applications which demonstrated his strong technology knowledge. The technology choice somewhat linked to the content and was used to some extent to teach the content. TG2 also had the ability to use technology representations to help students to understand the lesson concepts, and was able to use the same technology to link between different concepts and to provide examples. The evidence indicated that he had proficient technological content knowledge.

TG2 had an understanding of possible student misconceptions, knew how elements of the content could be arranged for better teaching, and demonstrated knowledge of teaching strategies that incorporate appropriate conceptual representations of the content in order to guide student thinking and learning. This indicated his proficient pedagogical and content knowledge. There was no compelling evidence to support the teacher’s use of pedagogical strategies and the ability to apply those strategies for use of technologies. He was somewhat able to guide students to use the technology to explore the content and objectives which reflected his proficient technological pedagogical knowledge. He mentioned the following in his review:

> *There were lots of pictures being looked up instead of materials and dimensions. This kills the creativity process of what was initially in their mind. Our next*

project should be a much smoother run. As for changes in the lesson prior to next year, I will definitely have useful websites that students can go to in order to get information and do research.

Overall, the teacher's TPACK was proficient. He used appropriate technology to enhance the content objectives and instructional strategies. He demonstrated the knowledge of how to teach concepts in easy ways and how technology enhances student learning.

CS2. CS2 was a 6^{th} grade mathematics teacher. The teacher prepared and taught a lesson on decimals. The lesson was well planned and consisted of objectives, standards, potential misconceptions, assessments, practices and activities, and potential re-teaching strategies. The technologies used in the lesson included Promethium board, student lap tops, and an iPad.

The lesson data, including planning and implementation, indicated that the teacher held strong understanding of procedural and conceptual understanding of the content knowledge. The active board allowed students to get up and out of their seats and to be engaged with the technology. The teacher (CS2) was somewhat able to use rules and procedures to engage students in learning. Student disruptions during the instruction were observed and students' misbehavior was sometimes ignored by the teacher. Her class activities reflected an understanding of developmental theory of learning and how students learn. The evidence indicated that she held proficient pedagogical knowledge.

The teacher also demonstrated knowledge of understanding and operating technology application in the actual lesson. She was able to use the technology application appropriately and showed proficient ability to learn and adapt new technology, as indicated in her reflection. She stated, "*I felt that the rounding activity that I found from promethean planet was a great resource to review rounding whole numbers and decimals.*"

The evidence showed that she had proficient technology knowledge. The technology choice suited the content. She demonstrated a strong ability to use technology representations to help students to understand the lesson concept and the effect of technologies on the content. CS2 was able to use the same technology to link between different contents or concepts and to provide examples as shown in the lesson plan. The evidence indicated that she held strong technological content knowledge. Although in her lesson plan included strategies for tackling student misconceptions, there was no evidence the strategies were implemented in the actual lesson. CS2 showed a lack of understanding in how elements of the content can be arranged for better teaching, and showed insufficient knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning. The teacher stated in her review that,

> *Overall, I felt like the lesson was a great idea, but there were some kinks that I need to work out before I do something like this again. The rotation stations are a good idea, and usually very successful. The problem that I faced was that the students had already done the activities in core math and when they got to enrichment, the students, even though they hadn't completed the stations weren't really wanting to work because it wasn't something new*.

The evidence indicated that she held proficient pedagogical and content knowledge. There was no strong evidence that indicated the teacher's ability to apply pedagogical strategies for use of technologies was strong. She was not able to guide students to use technology to explore content and objectives proficiently and was not able to use technology with appropriate pedagogical teaching strategies. For these reasons, CS2 was rated as marginal in technological pedagogical knowledge. The teacher demonstrated some ability to show how the use of appropriate technology and appropriate teaching strategies enhance instruction but was not able to use pedagogical techniques that use technology in constructive ways to teach content. There were student disruptions observed, however, and no disciplinary actions were taken by the teacher. Overall, the teacher's TPACK was marginal.

SB2. SB2 was a 9th grade algebra I teacher. Her lesson was titled "Exploring Inequalities with the Graphing Calculator." Her lesson plan consisted of objectives, standards, materials, engagement strategies, assessments and evaluation plans. Students solved inequalities using various methods, including tables, graphs, and algebraic methods. Students formulated equations and inequalities to represent problem situations, solved the equations and inequalities, and justified the final solutions in terms of the problem situation. Technologies used in the lesson were graphing calculators, Smartview calculator software, laptops, and projector.

The practicing data indicated that the teacher had strong mathematical language ability and used the language strategically and frequently. SB2 also demonstrated strong procedural and conceptual understandings of the content. The teacher ensured that students were actively involved in learning, resulting in no observed student misbehavior throughout the lesson. Her class activities reflected an understanding of developmental theory of learning and how students learn, and her oral assessments were appropriate. She showed strong pedagogical knowledge. In the lesson video, SB2 also demonstrated knowledge of understanding and operating technology application which indicated strong technology knowledge. The technology choices linked to the content taught and were used in a variety of ways in teaching the content. She showed the ability to use technology representations to help students to understand concepts and was able to use the same technology to link between different contents or concepts and to provide examples.

The evidence indicated that she held strong technological content knowledge. SB2 showed an understanding of possible student misconceptions, knowing how elements of the content can be arranged for better teaching, and the knowledge of teaching strategies that incorporate appropriate conceptual content representations to guide student thinking and learning. This indicated her strong pedagogical and content knowledge. There was lack of evidence that students' work on the graphing calculators was assessed. Her pedagogical strategies and the ability to apply those strategies for use of technologies was proficient. SB2 was able to guide students to use technology to explore the content and objectives. She demonstrated proficient technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technology to enhance the content objectives and instructional strategies. Overall she demonstrated the knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

AK2. AK2 was a 6th grade mathematics teacher. The teacher taught a lesson on fraction operation in which students used clickers to demonstrate their understanding of the concept of adding fractions. The detailed written lesson plan consisted of objectives, group cooperative learning activities, application problems used, and an evaluation plan. The teacher utilized the Promethean Board to demonstrate the concepts. Students solved problem in their notes, converted their answer into decimal form, and then entered their answers into their promethean clicker. Active class discussions occurred after all student solutions were presented.

The lesson was taught in a manner consistent with the lesson plan. AK2 implemented what she had planned. Her rationale for incorporating the technology in the lesson was supported in the technology research paper. The teacher stated,

> *It will require them to be more prepared for the lecture so that they can respond to the clicker questions, and forces them to consider the information more carefully during the instruction time so that they may synthesize the content when asked a clicker question about it.*

Her lesson analysis was consistent with her research findings about the technology used:

> *The technology really supports student learning though by using the clickers to monitor which students are getting it and which are not. I also love having the ability to do error analysis with the students*.

The lesson data indicated that AK2 had strong procedural and conceptual understanding of the content knowledge. Students were actively involved in learning and no classroom management issues were observed. Her class activities reflected an understanding of developmental theory of learning and how students learn which indicated her strong pedagogical knowledge. In the video, the teacher demonstrated knowledge of understanding and operating technology application which indicated that she had strong technology knowledge. The technology choices linked to contents and technology was used in many ways to teach the content. AK2 showed the ability to use technology representations to help students to understand the concept and she was able to use the same technology to link between different contents or concepts and to provide examples.

The evidence indicated that she held strong technological content knowledge. AK2 showed an understanding of possible student misconceptions, knowing how elements of the content can be arranged for better teaching, and the knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning. This evidenced her strong pedagogical and content knowledge. AK2 was also able to guide students to use technology to explore content and objectives, as evidenced in the video and in her technology research, demonstrated she had strong technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technologies to enhance content objectives and instructional strategies. She demonstrated the knowledge of what makes concepts difficult or easy to learn and how technology can help to enhance student learning.

AA2. AA2 was an 8^{th} grade algebra I teacher. The teacher taught a lesson entitled "Patterns and Percent QR Code Review Activity." The purpose of the lesson was for students to participate in a QR code review activity to prepare them for a percent and patterns unit exam. The teacher used the stock market to teach this concept. Students worked in groups and used their cell phones to scan posted QR codes that were prepared, and then answered related questions. Implementation of the lesson was consistent with the lesson plan. The teacher's integration of the technology rationale was guided by Kim and Freemyer's (2011) guiding technology integration principles. AA2 stated in her technology research that,

> *In the QR activity, all principles were met. Students were involved in real-world technology applications, although not an authentic inquiry, students were challenged with questions and challenged to discover the answers, scaffolding was incorporated with the code and collaboration with peers was probably the strongest principle used, since the students worked in groups throughout the entire activity*.

The practicing data indicated that AA2 held strong procedural and conceptual understanding of the content knowledge. The students were actively involved in learning, as shown in the video, and there was no evidence of classroom management issues. Her class activities shown in the video reflected an understanding of developmental theory of learning and how students learn, indicating that the teacher had strong pedagogical knowledge. The teacher demonstrated knowledge of understanding and operating technology application in the video which indicated that she had strong technology knowledge. The technology choices linked to contents and were used in different ways. AA2 showed the ability to use technology representations to help students understand the concept and was able to use the same technology to link between different contents. She asked students to go to the NASDAQ site, research how some of the companies they use (i.e., Facebook, Google, Instagram) were doing, and then use that data in their work. The evidence indicated she had strong technological content knowledge. She also showed an understanding of possible student misconceptions "*giving domain instead of the asked for* *range, or labeling the y-axis as the x,*" and knowledge of how content elements can be arranged for better teaching. As AA2 explained,

> *The next time I create a QR code lesson, I will make it a little longer. I knew we would spend some time discussing the NASDAQ reports, and some students took much longer than others, but a few more questions would be appropriate.*

AA2 demonstrated knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning. These indicated her strong pedagogical and content knowledge. She was able to guide students to use the technology to explore content and objectives, as evidenced in the lesson plan and video, indicating she held strong technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technology to enhance the content objectives and instructional strategies. She demonstrated the knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

PG3. PG3 was an 8th grade mathematics teacher. The lesson was titled as "Pasta Cars." The objectives of the lesson were for students to design, test, and redesign a pasta car, collect data, graph data using iPAD, make interpretations, and justify changes to students' designs. The lesson was well planned and consisted of standards, objectives, detailed instructions for exploring the concept, engagement, and evaluation plan. The implementation of the lesson was consistent with the lesson plan. The teacher's rationale for incorporating technology in this lesson was based on the literature that she gathered in her research. As she explained in her reflection,

> "*According to McCrory (2011) there are two considerations for the use of technology. First, use technology for parts of the lesson that are difficult to*

> *understand, and second, use technology for an important aspect of the lesson. Technology was used pedagogically in this lesson to plot the points on a graph to save time and to increase accuracy. Data was pooled together from all students to increase the number of points in the scatterplot*

Throughout the lesson, including planning and implementation, PG3 indicated strong procedural and conceptual understanding of the content knowledge. She gave clear instructions to ensure that students were actively involved in learning. Her class activities reflected an understanding of developmental theory of learning and how students learn. This evidence indicated she had proficient pedagogical knowledge. In the video, PG3 demonstrated knowledge of understanding and operating technology application, indicating she had strong technology knowledge. She also showed strong understanding of the linkage between technology and content, representation of concept using technologies, and an understanding of how content can be changed by the technology application. This demonstrated her strong technological content knowledge.

There was no evidence to indicate the teacher had an awareness of possible student misconceptions or knowledge of how content elements can be arranged for better teaching. PG3 stated that in the future she would change the order of the concepts being taught. Her thoughts were to "*teach the lesson after proportions and possibly equations so our class can have deeper discussions about the data and math and science concepts*." This included the knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning. The teacher added, "*We never determined who had the fastest car, or talked about science and math concepts, such as factors affecting speed, distance and time, or why the points* *were scattered so much*". PG3 had proficient pedagogical and content knowledge. There was no strong evidence that indicated the teacher's ability to apply the pedagogical strategies for use of technologies was proficient. She was able to guide students to use the technology to explore the content and objectives but was not able to complete the objectives.

> *The successful portions of the lesson were designing and creating the pasta cars as evidenced by student products. Students were able to collect data, enter it onto their collection sheet and online into tables with support. The lesson was not successful because it took a lot longer than I had anticipated*.

She showed proficient technological pedagogical knowledge. Overall, the teacher's TPACK was proficient. She used appropriate technology to enhance content objectives and instructional strategies even though the lesson did not complete the objectives. She demonstrated knowledge of what makes concepts difficult or easy to learn and how technology can help to enhance student learning.

MB4. MB4 was an 8th grade mathematics teacher who did a lesson on "Graphing Rate of Speed." The lesson was written comprehensively and consisted of objectives, standards, vocabulary and common misconceptions, materials, technologies, engagement, activities, and evaluation plan. From the class activities, students created a table of points from data collected, and then graphed the table of points in their phone or iPad mini. The implementation of the lesson was consistent with the lesson plan.

Analysis of the data indicated the teacher had strong procedural and conceptual understanding of the content knowledge. The iPad mini and phone allowed students to engage with activities. The activity reflected an understanding of MB4's developmental theory of learning and how students learn, and the oral assessments were relevant to the content. This evidenced the teacher's proficient pedagogical knowledge. MB4 also demonstrated knowledge of understanding and operating technology applications in the implementation of the lesson. She was able to manipulate technology applications herself and she showed the ability to learn and adapt to new technology. In the lesson plan, she listed all the technology applications, including the key features and instructions on how to use them. The evidence reflected her strong technology knowledge.

The technology was somewhat linked to the content. MB4 had the ability to use technology representations to help students to understand the concept taught, as well as the effect of technologies on the content. The evidence showed that she held proficient technological content knowledge. She stated possible student misconceptions in her lesson plan, used casual questions and posted questions related to misconceptions in the actual lesson. The teacher was able to arrange the activities in groups for better learning. This demonstrated her strong pedagogical and content knowledge.

There was no proficient evidence that indicated the teacher's ability to apply pedagogical strategies for use of technologies. MB4 was somewhat able to guide students to use the technology to explore the content and objectives, but student work could not be reviewed and discussed because of technical difficulties. The teacher acknowledged the issue in her writing: "*Unfortunately, more technical difficulties ensued and the footage of us attempting to create a spreadsheet was on a student's phone who was unable to get it to me since it was too large to email*." According to Mishra and Koehler (2006), the technology used should afford newer and more varied representations and greater flexibility in navigating across these representation. The evidence indicated that she had marginal technological pedagogical knowledge. Overall, the teacher's TPACK was proficient. She used appropriate technology to enhance the content objectives and instructional strategies although the technology choice was not the best for students to discuss their results. She demonstrated knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

AB4. AB4 was a 6^{th} grade mathematics teacher who prepared and taught a lesson on using tables, graphs, and equations to solve real-world problems. The lesson plan was well written and consisted of discretion, objectives, engagement, activities for exploration, elaborate and explain, and an evaluation plan. Students used a Desmos app on iPads to create tables, equations and graphs based on a word problem given in class. The teacher showed a simulation of the word problem from Geometer's Sketchpad for student discussion. The actual lesson implementation was consistent with the lesson plan. The teacher provided relevant literature for her rationale for the technology integration in the lesson. She stated the following in her research: "*I decided to teach this lesson this way because I thought the Desmos app really created a neat visual for students to be able to see how the table, equation, word problem, and graph are all interrelated.*"

The practicing data indicated that the teacher had strong mathematical language ability and used language strategically and frequently. AB4 also demonstrated strong procedural and conceptual understanding of content knowledge. The teacher ensured that students were actively involved in learning and there were no classroom management issues. Her class activities reflected an understanding of developmental theory of learning and how students learn, and her oral assessments were appropriate. For these reasons, she was rated with strong pedagogical knowledge.

In the video, AB4 demonstrated knowledge of understanding and operating technology applications (Geometer's Sketchpad and Desmos app), indicating she had strong technology knowledge. The technology choices linked to content and were used in many ways in teaching the content. She showed the ability to use technology representations to help students to understand the concept and she was are able to use the same technology to link between different contents or concepts and provided examples, as shown on the Geometer's Sketchpad. The evidence indicated that she held strong technological content knowledge.

AB4 demonstrated an understanding of possible student misconceptions (as shown in the lesson plan), knowing how elements of the content can be arranged for better teaching, and knowledge of teaching strategies that incorporate appropriate conceptual representations of content to guide student thinking and learning. This indicated her strong pedagogical and content knowledge. Her pedagogical strategies and the ability to apply those strategies for use of technologies was proficient.

She was able to guide students to use the technology to explore the content and objectives, although a few students struggled to write equations at the end after connect representations on the iPad. She showed proficient technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technology to enhance the content objectives and instructional strategies. Overall she demonstrated the knowledge of what makes concepts difficult or easy to learn and how technology can help to enhance student learning.

KT3. KT3 was a 9th grade algebra I teacher who planned and taught a lesson on "Solving Literal Equations." The lesson was intended to provide students with the opportunity to solve literal equations using technology to check their answers. The lesson plan was well written, including objectives, standards, vocabularies and materials, instruction and group activities, discussions of group work, and evaluation plan. The actual lesson implementation was consistent with the lesson plan, however. The teacher provided relevant literature for her rationale for the technology integration in this lesson. KT3 stated the following in her research:

> *One theory I am using is that of Gardner's Multiple Intelligences. The computer station requires the students to describe in words the steps they must take in order to solve a problem. This is helpful for the students who think more linguistically. Students with the linguistic intelligence have a "sensitivity to the spoken and written word" (Helding, 2009). It can help them to think through the process,* and *gain a clearer understanding. These students often struggle with abstractions and can benefit from recording the steps from an abstraction verbally, so that they know exactly what they are doing, why they are doing it, and how to get the end result of each step… Students who are more logical/mathematical thinkers will benefit from most of the other stations, in which they use inverse operations in order to isolate a certain variable.*

The actual lesson data indicated that KT3 had strong procedural and conceptual understanding of the content knowledge. The students were actively involved in learning as shown in the video, and there was no evidence of classroom management issues. Her class activities reflected an understanding of developmental theory of learning and how students learn. The teacher provided two review questions from a previous quiz as warm up. Students actively worked at four different stations which included use of different technologies for learning the content. The evidence indicated KT3 had strong pedagogical knowledge. As evidenced in the video, the teacher demonstrated knowledge of understanding and operating technology application which indicated that she has strong technology knowledge. The technology choices linked to content and were used in different ways. She exhibited the ability to use technology representations to help students to understand concepts and was able to use the same technology to link between different contents. This indicated that she has strong technological content knowledge.

KT3 demonstrated an understanding of possible student misconceptions (she asked leading questions to help students understand their mistakes during a group work on whiteboard) and knowing how elements of the content can be arranged for better teaching. She also showed knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning. One of the stations used iPads that provided students the visual representations of the concept. These aspects of her practice indicated her strong pedagogical and content knowledge.

She was also able to guide students to use the technology to explore content and objectives. The questioning strategy implemented during the whiteboard activity worked out well. KT3 mentioned the use of the Socrative app in her research, stating, "…*reason is because this app allows for automatic feedback for the students as well as the teacher*." This was evidenced in both the lesson plan and the video. It indicated that she held strong technological pedagogical knowledge. Overall, the teacher's TPACK was strong. She used appropriate technology to enhance the content objectives and instructional strategies. She demonstrated knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

MM3. MM3 was a 7th grade mathematics teacher. She planned and taught a lesson on fractions and decimals. The lesson was written comprehensively and consisted of objectives, engagement, activities, elaboration, and evaluation of students' understandings of the concept. Students used EduCreations, a story telling technology, to create small, personal libraries of story summaries to be used by them in preparation for the STAAR test. She cited the literature that supported her rationale for the integration, writing, "*Instructional technology and content-specific work in tandem to develop understanding of digital storytelling as an educational tool (Dreon, Kerper & Landis, 2011*." The implementation of the lesson was consistent with the lesson plan.

The analysis of data indicated that MM3 had strong understanding of procedural and conceptual understanding of the content knowledge. The activity reflected an understanding of teacher's developmental theory of learning and how students learn. In addition, oral assessments were relevant to the content. These aspects reflected the teacher's proficient pedagogical knowledge. The teacher demonstrated knowledge of understanding and operating technology application in the implementation of the lesson. She was able to manipulate the technology application herself and she had the ability to learn and adapt new technology. She stated,

> *There is a learning curve to using technology. Continued use of the software improves this, but it takes a while. Since I have been using Educreations, I have learned most of the things that can go wrong. I am easily able to fix it if it will not record at all, by making sure the microphone is enabled*.

The evidence reflected her strong technology knowledge. The technology linked to the content. She exhibited the ability to use technology representations to help students to retain the information they learned and the effect of technologies on the content. The evidence indicated that she had strong technological content knowledge. The teacher was able to arrange the contents necessary based on class progress. This evidence indicated she held proficient pedagogical and content knowledge.

There was no proficient evidence that indicated MM3's ability to apply pedagogical strategies for use of technologies. She was somewhat able to guide students to use the technology to explore the content and objectives, but the teacher was the only one using the technology to explain students' works during the discussion. Students had limited involvement in using technology to explain their work. The evidence indicated that MM3 had marginal technological pedagogical knowledge. Overall, the MM3's TPACK was proficient. She used appropriate technology to enhance content objectives although the instructional strategies using the technology were not the best for providing opportunities for students to discuss their results. She demonstrated the knowledge of what makes concepts difficult or easy to learn and how technology can help to enhance student learning.

TT3. TT3 was an 8^{th} grade mathematics teacher who taught a lesson named "Volume of Prisms/Cylinders and Pyramids/Cones." Her lesson plan used the 5E model which included engage, explore, explain, elaborate, and evaluate. The objectives of the lesson were to help students make predictions, find relationships, write formulas, and solve application problems with the help of a partner or whole group discussion. The implementation of the lesson was consistent with the lesson plan. The teacher's rationale for incorporating technology (Socrative) in this lesson was described in her technology research. She wrote:

Electronic tools to support the teaching of mathematics can be an important part of teachers' resources for promoting student learning of mathematics" (Hollenback, 2009). The use of technology can be a great way to get students enthusiastic about their learning. By using the students' tablets and smart phones, I am able to communicate with the students in a new and exciting way. This also allows me to communicate with written communication – since most of the questions were short answer – which is allowing the students to practice with writing in mathematics.

Throughout the lesson, including the planning and implementation, TT3 indicated strong procedural and conceptual understandings of the content knowledge. The teacher gave clear instructions to ensure that students were actively involved in learning. There was a lot of discussion among students and teacher. Her class activities reflected an understanding of developmental theory of learning and how students learn. This evidence indicated that she had strong pedagogical knowledge.

In the lesson video, TT3 demonstrated knowledge of understanding and operating technology applications which indicated her strong technology knowledge. She had an understanding of the linkage between technology and the content, representation of concept using technologies, and an understanding of how content can be changed by the technology application. This evidenced her proficient technological content knowledge. The teacher exhibited an awareness of possible student misconceptions. She used oral assessment constantly to tackle the students' misunderstanding. She also demonstrated understanding how content elements can be arranged for better teaching, and knowledge of teaching strategies that incorporate appropriate conceptual representations of the content in to guide student thinking and learning. In her reflections, TT3 included the following comment:

> *As far as teacher role, I believe I was a facilitator or guide. I instructed the students to fill out the questions prior to the activity that asked them to make predictions about what the relationship was between the prism and pyramid. The students were asked (with Socrative) to compare the base and height of the two solids (that were physically present) and then I performed the demonstration.*

TT3 showed strong pedagogical and content knowledge. There was no strong evidence that indicated the teacher's ability to apply the pedagogical strategies for use of technologies. She was able to use technology to gather data from students and to provide feedback, but there was no evidence that indicated that technology was employed to guide students to explore content and objectives. TT3 explained, "*Using the handheld technology, I was able to obtain immediate data from the students and in turn, give immediate feedback and guidance as necessary. All of the students that had their hand-held device were engaged in the activity.*" She had proficient technological pedagogical knowledge. Overall, the teacher's TPACK was proficient. She used somewhat appropriate technology to help students to learn the content objectives and to aid her instructional strategies. She demonstrated the knowledge of how to teach concepts in easy ways and how technology can help to enhance student learning.

CB4. CB4 was a 5th grade mathematics teacher. He planned and taught a lesson on "Storytelling in Mathematics." His lesson plan consisted of detailed information about what would happen in class. It included objectives, standards, introductory, materials, lesson activities, extension, closure, and evaluation plan. The implementation of the lesson was consistent with the lesson plan. The teacher's research finding in the literature supported his rationale for the lesson. He stated:

> *Storied math context helps students engage both emotionally and cognitively with mathematics and helps show that mathematics develops out of human experience. Students were engaged in the stories that I read to them. Knowing that students have had previous exposure to mathematics literature, I used this a springboard for discussion with students.*

The teacher implemented what was planned in the lesson. The lesson data indicated that the teacher had strong understanding of procedural and conceptual understanding of the content knowledge. The students were actively involved in learning and no evidence of classroom management issues was observed. His class activities reflected an understanding of developmental theory of learning and how students learn which indicated his strong pedagogical knowledge.

CB4 demonstrated knowledge of understanding and operating technology application which indicated that he held strong technology knowledge. The technology choices linked to content and technology was used in multiple ways to teach the content. He exhibited the ability to use technology representations to help students to understand the concept and was able to use the same technology to link between different contents or concepts and provide examples. In his reflections, CB4 stated:

> *I read to the students, two selected stories involving money (quarters) at a lemonade stand and dividing up fruit at a gathering… The technology supported the students becoming vested in their story, using their imagination, and to further tell their story.*

This evidence indicated that he held strong technological content knowledge.

CB4 exhibited an understanding of possible student misconceptions and knowing how elements of the content can be arranged for better teaching. He also demonstrated knowledge of teaching strategies that incorporate appropriate conceptual representations of the content to guide student thinking and learning that indicated her strong pedagogical and content knowledge. He was able to guide students in the use of digital storytelling technology to explore the content and objectives, as evidenced in the lesson video and in his technology research. The evidence indicated that CB4 had strong technological pedagogical knowledge. Overall, the teacher's TPACK was strong. He used appropriate technology to enhance the content objectives and instructional strategies. He demonstrated the knowledge of what makes concepts difficult or easy to learn and how technology can help to enhance student learning.

Chapter V

Discussion

Summary

The purpose of this study was to characterize middle-grade mathematics teachers' TPACK during their classroom practice by examining their practicing data. These fifteen teachers were enrolled in a graduate course about using technology in instructional practices. The intent of the study was to develop and use a rubric to analyze a lesson cycle data of these fifteen middle-grade in-service mathematics teachers in order to learn what their TPACK looked like in the classroom practice. Archival data from the coursework included teachers' lesson plans, video tapes of lessons, teachers' technology research papers, and teacher reflections on the lesson after implementation.

This study was conducted in two phases. In phase one, this researcher developed a rubric for characterizing the mathematics teachers' TPACK in practice, using construct analysis (Cox, 2008) and working through multiple rounds of analysis and revision. Interrater reliability of the rubric was examined using Intraclass Correlation (0.734). Internal consistency within the rubric was computed using Cronbach's Alpha (P=0.007).

In phase two, the lesson cycle assignment data of the fifteen middle-grade mathematics teachers was applied to the rubric for characterization of their TPACK. Descriptive, observational, and video and content analysis methods were used to analyze the mathematics teachers' data during the process. The results were organized in a TPACK characterization pattern chart that showed these teachers' TPACK level (weak to strong) for the pattern observation as shown in Figure 4 (page 46). The lesson cycle assignment, which represented how teachers operationalized their TPACK in practice, included a written lesson plan, videotape of implementation of the lesson, reflections about the lesson, and a brief literature review about the chosen technology of the lesson. The lesson cycle assignment was archived data in Blackboard Learn at the university that the study was conducted.

Conclusions

In this section, the findings of the study will be discussed, beginning with an overview of the rubric analysis and followed by an examination of the individual knowledge components considered in this study.

Overview of findings. The lesson cycle data of the fifteen mathematics teachers' was applied to the rubric and results were organized in the TPACK characterization pattern chart (see Figure 4, p. 46). A color coding method was used for observations to characterize the teachers' knowledge from strong to weak (Green = Strong; Blue = Proficient; Orange = Marginal; and Red = Weak). The chart showed a visible pattern for each teacher's seven TPACK components.

When looking at individual components separately (see Figures 7 and 8), the teachers as a group demonstrated strong knowledge in three basic knowledge components of the TPACK. These were content knowledge (CK), technology knowledge (TK), and pedagogical knowledge (PK). The teachers' combined PK, however, was somewhat more proficient and less strong than the other two components. Another significant pattern that emerged in the chart analysis was that the teachers' knowledge strength decreased on three of the four combined knowledge components—pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and the combination of the three components of their technological pedagogical and content knowledge (TPACK). The teachers' TPK demonstrated the most marginal and least strong levels among all components (Figures 7 and 8). Their technological content knowledge (TCK) was relatively the strongest among the combined knowledge components, with 80% of teachers rated strong and 20% proficient. The teachers' strong TCK was constant with their strong CK and TK.

	Technological Pedagogical and Content Knowledge						
	CK	PK	TK	TCK	PCK	TPK	TPACK
Weak	0%	0%	0%	0%	0%	0%	0%
Marginal	0%	0%	0%	0%	7%	27%	13%
Proficient	0%	40%	7%	20%	33%	33%	40%
Strong	100%	60%	93%	80%	60%	40%	47%

Figure 7. The percentage of scale-characteristics of the teachers' TPACK

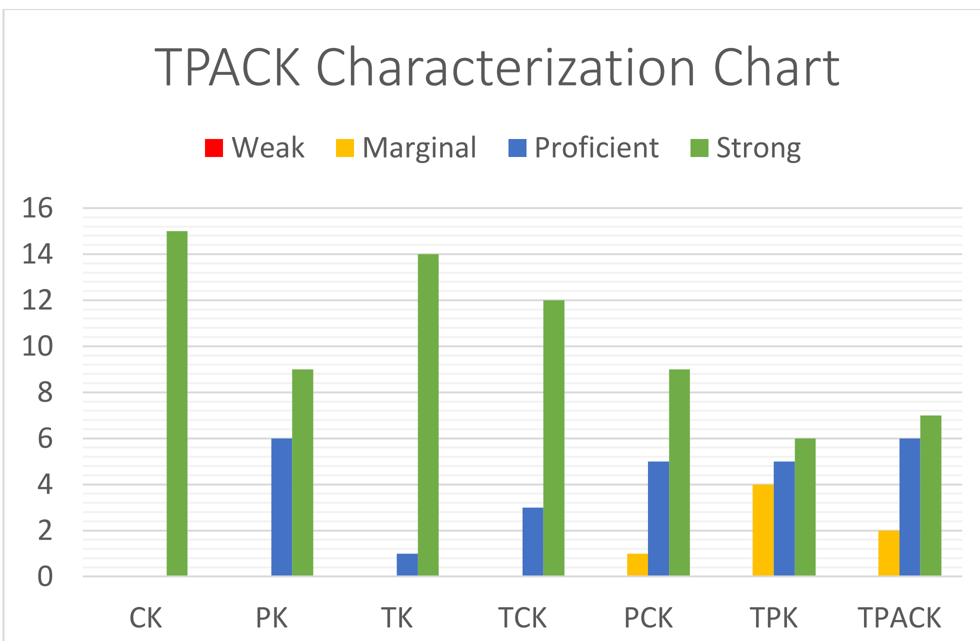

Figure 8. TPACK characterization chart

CK. There was no red (representative of weak knowledge) found among these mathematics teachers in any of the seven components. All teachers (100%) indicated strong content knowledge (CK) which was the result of their ability to apply procedures accurately, their strong understanding of concepts being taught, and their ability to use those concepts strategically to solve problems that were evident in the data. All teachers demonstrated proficient mathematical language ability and used the language strategically and frequently. The teachers' experienced status may have contributed to their strong CK result. This aligns with research which evidenced a stronger CK in more experienced teachers due to the relation between teachers' disciplinary content knowledge and their instructional practices (Cai, 2005; Iszak, 2008; Sowder, Phillip, Armstrong, & Schappelle, 1998; Thompson & Thompson, 1996; Thompson & Thompson, 1994; Wilson, 1994).

TK. Fourteen out of fifteen (93%) teachers indicated strong technology knowledge (TK) based on the results of the study. Only one teacher was found to be proficient in TK. This result provides further evidence that technologies have been increasingly used in today's classrooms and that, equally, teachers have increased their proficiency in the personal and professional uses of technology (Ertmer & Ottenbreit-Leftwich, 2010; Project Tomorrow, 2007). In response to the Speak Up survey in Project Tomorrow (2007), seventy-five percent (75%) of participating teachers noted their students were more engaged as a result of technology and reported corresponding increases in student achievement (Project Tomorrow, 2007). Increased student interest, engagement, and achievement may have been a factor in promoting the TK of teachers in this study.

PK. Results of the study also showed that nine out of fifteen (60%) teachers held a strong pedagogical knowledge (PK) and six out of fifteen (40%) teachers evidenced proficient PK. Compared to CK (100% strong) and TK (93% strong), the teachers' PK

(60% strong) which is the knowledge of teaching strategies was rated as less strong (Figures 7 and 8 above). In other words, compared to their disciplinary area knowledge and knowledge of technology, the teachers' understanding of how students learn, general classroom management skills, and student assessment were less strong. This result drew attention to the understanding that good teaching requires teachers to expand their knowledge of pedagogical practices across multiple aspects of the planning, implementation, and evaluation (Ertmer, & Ottenbreit-Leftwich, 2010). It also illustrated the positive or negative effect of PK levels on the complex knowledge components (i.e., TPK, CPK, TPACK).

TCK. The first of the combined knowledge components analyzed was technical content knowledge (TCK). Findings showed that twelve out of fifteen teachers had a strong (80%) TCK, and three teachers demonstrated proficient (20%) TCK. This result was aligned with the teachers' strong CK and TK components. Additionally, the combination of the two strong knowledge components, CK (100% strong) and TK (93% strong) positively affected the formation of a relatively stronger TCK (80% strong). This result suggested that the teachers had both strong abilities to use technology representations to teach content and strong understandings of the links between technologies and content.

PCK. Nine out of fifteen (60%) teachers indicated strong pedagogical content knowledge (PCK), five (33%) showed proficient PCK, and one (7%) had marginal PCK. These PCK ratings aligned with the teachers' relatively lower PK (60% strong)—an integral component of their PCK. These PCK ratings somewhat contradicts Archambault and Crippen's (2009) findings that teachers often feel strongly about their ability to deal with issues related to pedagogy and content, but more hesitant when it comes to issues dealing with technology. The findings of Archambault and Crippen's research were likely related to level changes in the teachers' technology abilities and confidence as a results significant technology development and integration in education in recent years.

TPK. In regards to technological pedagogical knowledge (TPK), six out of fifteen (40%) teachers showed a strong TPK, five out of fifteen (33%) teachers indicated proficient TPK, and four out of fifteen (27%) teachers demonstrated marginal TPK. According to the results, teachers' TPK was the relatively weakest among all components of the TPACK. Teachers' relatively lower PK could possibly have been a contributing factor to their lower TPK. This result was consistent with the pattern found in this study in that teachers' combined knowledge components were weaker than their three single knowledge components, such as CK (100% strong), PK (60% strong), and TK (93% strong). Teachers' TPK ratings in this study provided further evidence of teachers' inefficient use of technology, supporting literature on the subject. Recent research (Bauer & Kenton, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Project Tomorrow, 2008) suggested that teachers/educators have not yet achieved high levels of effective technology use, either in the United States or internationally (Kozma, 2003; Mueller, Wood, Willoughby, Ross, & Specht, 2008; Smeets, 2005; Tondeur, van Braak, & Valcke, 2007a). Furthermore, recent research suggested that if and when technology was used in the classroom, it typically was not used to support the kinds of instruction believed to be most powerful in facilitating student learning (Ertmer & Ottenbreit-Leftwich, 2010).

TPACK. Similar to other combined ratings, the teachers' combined knowledge of TCK (80% strong), PCK (60% strong), and TPK (40% strong) formed a relatively weaker technological pedagogical content knowledge (TPACK)—the most complex knowledge in the framework. Seven out of fifteen (47%) teachers showed a strong TPACK, six (40%) teachers demonstrated proficient TPACK, and two (13%) teachers indicated marginal TPACK. This result seemed obvious because of TPACK was the combination of already weaker TPK, PCK, and TCK.

Summary comments. Results of the study provided detailed characteristics of these fifteen mathematics teachers' knowledge. They appeared to have solid knowledge of CK, PK, and TK according to the analysis. Consistently, the CK, PK, and TK formed relatively weaker knowledge characteristics when combining these three knowledge components (see Figure 7). These results provided further evidence of how CK and PK, CK and TK, and PK and TK intersect in the TPACK framework described by Mishra and Koehler (2006). Although the teachers' three single knowledge components were strong, the teachers' knowledge characteristics were weakened when these single knowledge components intersected with each other. Results also indicated that the PCK, TPK, and TPACK associated with PK demonstrated relatively weaker knowledge characteristics than TCK, which did not include the PK component. Additionally, this result further emphasized the importance of, and the difficulties in, acquiring pedagogical knowledge which requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in their classroom (Mishra, & Koehler, 2006; Shulman, 1986).

The rubric developed in this study demonstrated validity reliability in analyzing the practicing data and evaluation of teachers' TPACK levels. The TPACK characterization chart promoted the effective organization of the data analysis results.

The findings helped to answer the guiding question of this study which was: In what ways can we characterize middle school mathematics teachers' TPACK? Utilizing a specific rubric that was developed using pilot data to analyze teachers' comprehensive practicing data (i.e., lesson cycle which represented how teachers operationalized their TPACK in practice) facilitated the characterization and understanding of the middle school in-service mathematics teachers' TPACK by characterizing each component into weak, marginal, proficient, and strong levels.

Recommendations

A number of recommendations emerged from this study regarding teaching training, rubric development, and future research.

Teacher training. One of the important findings in this study was that teachers' TPK proved to be the weakest component of all seven TPACK components. This finding could be used to inform the design of course work for pre-service and in-service teachers. Findings also suggested the need for teacher education or professional development programs to increase the focus on developing mathematics teachers' TPK, or more specifically, the strategies to engage and to guide students in using technologies to explore and learn content. In addition, the development of PK needs to be a continuous priority in teacher education programs. The results of this study suggested that mathematics teachers' lower PK could be one of the factors keeping other combined knowledge components (including TPACK) at a weaker level. It was not surprising, however, that PK, the knowledge of teaching strategies, was shown to be a difficult knowledge to acquire. For these reasons, those knowledge components of teachers' TPACK that contain PK (i.e., PCK, TPK, and TPACK) should be greatly emphasized when providing trainings for both pre- and in-service teachers. This supports a recommendation to reevaluate teaching methods courses for both university and alternative certification program (ACP) undergraduate students in order to improve pre-service teachers' PK that may affect other knowledge components of their TPACK.

Rubric development. In regards to the rubric developed and utilized in this study, it is recommended that the rubric be further tested to improve its usability, reliability, and validity. For example, the interrater reliability of the rubric could be improved to its optimum level by further examining the rating descriptions of the rubric in order to more accurately characterize the different components of teacher knowledge. Additional testing of the rubric (applying the rubric to new sets of participants) would also improve rubric reliability and validity, and perhaps indicate modifications needed.

Further research. There are also several recommendations related to future research, the first of which deal with data quantity and collection. For the purpose of this study, only complete Lesson Cycle submissions data was used for analysis. The more Technology Lesson Cycle submission data can be used for analysis, the more precise pattern of teachers' TPACK characteristics may be generated.

For the next step, in-service mathematics teachers' TPK needs to be further studied to understand what makes this particular component weaker than CK, PK, TK, TCK, PCK, and TPACK. Further studies would potentially provide additional recommendations for what needs to be done to improve teachers' TPK, as well as other components of TPACK in general.

Limitations of the Study

In order to fully evaluate the relevance and impact of this study's findings, the limitations of the study were fully explored in regards to data, impact, and design. The first point considered regarding data was that the participants were a unique group of teachers enrolled in an online graduate course for the M.Ed. degree at the university. Due to the fact that the data was used for a course grade (which could have contained potential sources of bias and exaggeration), the data may not have reflected the teachers' true ability or TPACK level. Another limitation was the use of archival data in regards to teacher interviews in that it prohibited this researcher's ability to conduct direct interviews with teachers which may have yielded a deeper understanding of their experiences in designing and implementing technology-integrated mathematics lessons.

There was also a possible impact limitation since all teachers in this study were middle-grade teachers. For this reason, the results may not have been applicable to all in-service mathematics teachers across grade levels from elementary to senior high school. Finally, although the rubric developed for this study reached an adequate level of the interrater reliability, it did not reach the optimum level that is recommended in the literature which may have affected accurate data analysis.

Concluding Thoughts

Teachers' knowledge and abilities have the greatest impact in students learning. To have a positive impact in the classroom when doing so, mathematics teachers need to have a deep and broad understanding of the content they teach, pedagogical knowledge of how students learn, and technology knowledge of how technology supports student learning. In addition, teachers need to have the ability to use technology representations to teach contents (TCK), to rearrange the contents based on students' cognitive ability (PCK), to use strategies to engage and guide students exploring and learning contents with technology (TPK), and to use appropriate technology enhance contents with effective teaching strategies (TPACK).

To help teachers to develop these knowledge, we need to understand or characterize mathematics teachers' TPACK in practice. Characterizing teachers' TPACK in their teaching practice in a comprehensive way will serve to expand the understanding of teachers' TPACK, and will help teacher educators to understand how mathematics teachers develop TPACK. This will then inform the design of professional development aimed at developing teachers' TPACK.

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Appendix A

TPACK Component Definitions

CONTENT KNOWLEDGE

Content knowledge (CK) is "knowledge about the actual subject matter that is to be learned or taught. The content to be covered in high school social studies or algebra is very different from the content to be covered in a graduate course on computer science or art history. Clearly, teachers must know and understand the subjects that they teach, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organize and connect ideas; and knowledge of the rules of evidence and proof" (Shulman, 1986). "Teachers must also understand the nature of knowledge and inquiry in different fields. For example, how is a proof in mathematics different from a historical explanation or a literary interpretation? Teachers who do not have these understandings can misrepresent those subjects to their students" (Ball & McDiarmid, 1990).

PEDAGOGICAL KNOWLEDGE

Pedagogical knowledge (PK) "is deep knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation, and student evaluation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge, acquire skills, and develop habits of mind and positive dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in their classroom" (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

PEDAGOGICAL CONTENT KNOWLEDGE

The idea of pedagogical content knowledge is consistent with, and similar to, Shulman's idea of knowledge of pedagogy that is applicable to the teaching of specific content. This knowledge includes knowing what teaching approaches fit the content, and likewise, knowing how elements of the content can be arranged for better teaching. This knowledge is different from the knowledge of a disciplinary expert and also from the general pedagogical knowledge shared by teachers across disciplines. PCK is concerned with the representation and formulation of concepts, pedagogical techniques, and knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge, and theories of epistemology. It also involves knowledge of teaching strategies that incorporate appropriate conceptual representations in order to address learner difficulties and misconceptions and foster meaningful understanding. It also includes knowledge of what the students bring to the learning situation, knowledge that might be either facilitative or dysfunctional for the particular learning task at hand. This knowledge of students includes their strategies, prior conceptions (both ''naive'' and instructionally produced), misconceptions that they are likely to have about a particular domain, and potential misapplications of prior knowledge (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

TECHNOLOGY KNOWLEDGE

Technology knowledge (TK) is knowledge about standard technologies, such as books, chalk and blackboard, and more advanced technologies, such as the Internet and digital video. This involves the skills required to operate particular technologies. In the case of digital technologies, this includes knowledge of operating systems and computer hardware, and the ability to use standard sets of software tools such as word processors, spreadsheets, browsers, and e-mail. TK includes knowledge of how to install and remove peripheral devices, install and remove software programs, and create and archive documents. Most standard technology workshops and tutorials tend to focus on the acquisition of such skills. Since technology is continually changing, the nature of TK needs to shift with time as well. For instance, many of the examples given above (operating systems, word processors, browsers, etc.) will surely change, and maybe even disappear, in the years to come. The ability to learn and adapt to new technologies (irrespective of what the specific technologies are) will still be important (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

TECHNOLOGICAL CONTENT KNOWLEDGE

Technological content knowledge (TCK) is knowledge about the manner in which technology and content are reciprocally related. Although technology constrains the kinds of representations possible, newer technologies often afford newer and more varied representations and greater flexibility in navigating across these representations. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology. For example, consider Geometer’s Sketchpad as a tool for teaching geometry. It allows students to play with shapes and form, making it easier to construct standard geometry proofs. In this regard, the software program merely emulates what was done earlier when learning geometry. However, the computer program does more than that. By allowing students to ‘‘play’’ with geometrical constructions, it also changes the nature of learning geometry itself; proofs by construction are a form of representation in mathematics that was not available prior to this technology. Similar arguments can be made for a range of other software products (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE

Technological pedagogical knowledge (TPK) is knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. This might include an understanding that a range of tools exists for a particular task, the ability to choose a tool based on its fitness, strategies for using the tool’s affordances, and knowledge of pedagogical strategies and the ability to apply those strategies for use of technologies. This includes knowledge of tools for maintaining class records, attendance, and grading, and knowledge of generic technology-based ideas such as WebQuests, discussion boards, and chat rooms (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

Technological pedagogical content knowledge (TPCK) is an emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology). This knowledge is different from knowledge of a disciplinary or technology expert and also from the general pedagogical knowledge shared by teachers across disciplines. TPCK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

Appendix B

Assignments and Descriptions

CUIN 6346 Teaching Secondary Mathematics (and Science) with Technology

Technology Lesson Cycle

This is a full lesson that uses technology that you develop (or revise from a previous lesson that you have taught), implement & videotape, analyze, and revise. What you will submit on your due date:

1) A) The written lesson plan – you may use any format, but it must be detailed enough for the reader to discern what was taught and how it was taught.
   B) You must also include an evaluation plan that indicates how you will know that your students learned the content that you were teaching.
2) What learning theories are you using? This should be no more than two double-spaced pages describing what models or theories of how children learn the content that are informing the design of your lesson. Cite literature where relevant.

3) Research/literature about technology – what research/literature specific to technology supports your instructional and technological decisions for this lesson (No more than 2 double-spaced pages! Provide at least 4 citations, APA style)

4) At least 20 minutes of video-taped instruction of the lesson. This can be raw or edited. We want to see how the technology was implemented and ways that the technology facilitated (or did not facilitate) learning.

5) Your description and analysis of the video and the lesson overall:
   a. Describe what we are seeing in the video; include what you were thinking at the time
   b. Specifically describe ways in which the technology is supporting or hindering learning of the concept. This should be supported in the video.
   c. Was the lesson successful? What evidence are you using to support your claims?

6) Your revisions: What changes will you make to the lesson and why?

Lesson Cycle Due Dates

Oct 30: Student 1, Student 2, Student 3, Student 4, Student 5, Student 6, Student 7
Nov 6: Student 8, Student 9, Student 10, Student 11, Student 12, Student 13, Student 14
Nov 13: Student 15, Student 16, Student 17, Student 18, Student 19, Student 20
Nov 20: Student 21, Student 22, Student 23, Student 24, Student 25, Student 2

Appendix C

Initial Rubric Used to Analyze Teachers' TAPCK in Practice

(CUIN 6346 Lesson Cycle Assignment)

Teacher name:
Grade level:
Class:
Lesson:

Initial Rubric Use to Analyze Mathematics Teachers' TPACK in Practice

(CUIN 6346 Lesson Cycle Assignment)

Data sources: The written lesson; teacher reflections about the lesson; evidence of learning outcomes provided by the teacher; video of implementation
(The scale 1-5 represents: Weak; Low-Medium; Medium; Medium-High; and Strong)

TPACK Components	Criteria	Scales (1 Low – 5 High)					Evidence (examples presented in the data that led to the rating)		Overall Rating (Circle the one Applies)
		1	2	3	4	5	Present	Not Present	
Content Knowledge (CK)	D. Content been taught								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445) **Strong** (455; 555)
	E. Procedural understanding of content								
	F. Conceptual understanding of content								
Pedagogical Knowledge (PK)	A) Appropriate assessments								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium**
	B) Organize and manage student behavior (Explain sequence of events and procedures for students)								

	C) Class activities reflect an understanding of developmental theory of learning and how students learn								(233; 333; 334) **Medium High** (344; 444; 445) **Strong** (455; 555)
Technological Knowledge (TK)	A) Knowledge of the technology application								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445) **Strong** (455; 555)
	B) Demonstrates understanding of technology as teacher tool or student tool								
	C) The ability to learn and adapt to new technologies								
Technological Content Knowledge (TCK)	A) Link between technology and content is obvious or explicit								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445) **Strong** (455; 555)
	B) An understanding of the representation of concepts using technologies								
	C) An understanding of the content can be changed by the application of technology								
Pedagogical Content Knowledge (PCK)	A) Demonstrates awareness of possible student misconceptions								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445)
	B) Knowing how elements of the content can be arranged for better teaching								
	C) Knowledge of teaching strategies								

	that incorporate appropriate conceptual representations of the content in order to guide student thinking and learning, and address learner difficulties and misconceptions.								**Strong** (455; 555)
Technological Pedagogical Knowledge (TPK)	A) Evidence of appropriate technologies enhancing student learning (student centered approaches) – Students use technology to explore content and achieve learning goals								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445) **Strong** (455; 555)
	B) Knowledge of how technologies can be used to build on existing knowledge and to develop new ones or strengthen old ones.								
	C) Knowledge of pedagogical strategies and the ability to apply those strategies for use of technologies								
Technological Pedagogical and Content Knowledge (TPACK)	A) Appropriate technology enhances content objectives and instructional strategies								**Weak** (111;121) **Low Medium** (122; 222; 223) **Medium** (233; 333; 334) **Medium High** (344; 444; 445) **Strong**
	B) Demonstrate the knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face								

	C) Pedagogical techniques that use technologies in constructive ways to teach content								(455; 555)

Appendix D

Final Rubric Used to Analyze Teachers' TPACK in Practice

(CUIN 6346 Lesson Cycle Assignment)

Teacher name:
Grade level:
Class:
Lesson:

Rubric Use to Analyze Mathematics Teachers' TPACK in Practice

(CUIN 6346 Lesson Cycle Assignment)

Data sources: The written lesson; teacher reflections about the lesson; evidence of learning outcomes provided by the teacher; video of implementation
(The scale 1-4 represents: Weak; Marginal; Proficient; and Strong)

TPACK Components	**Criteria**	**Category (1 Weak – 4 Strong)**					**Overall Rating (circle one)**
		1	**2**	**3**	**4**	**Score**	
Content Knowledge (CK)	A) Procedural understanding of content	Apply procedures poorly, or inefficiently;	Ability to apply procedures somewhat accurately and efficiently,	Proficient in applying procedures accurately and efficiently; transfer procedures to different problems and contexts	Strong ability to apply procedures accurately, efficiently, and flexibly; transfer procedures to different problems and contexts		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Conceptual understanding of content	Lack of ability to understand concepts being taught and encounter difficulties when use them to solve problems	Understanding concepts being taught and able to use them to solve problems with difficulty	Understanding concepts being taught and able to use them strategically to solve problems	Strong understanding of concepts being taught and able use them strategically to solve problems; strong ability to identify misconceptions		
	C)Mathematical languages	Minimum or no mathematical language	Appropriate use of mathematical language	Sufficient mathematical language and use them appropriately and frequently	Strong mathematical language ability and use the language strategically and frequently		

Pedagogical Knowledge (PK)	A) Appropriate assessments	Assessments are less or not relevant to the concepts being taught and do not reflect teachers' understanding of students' cognitive abilities	Assessments are somewhat relevant to the concepts being taught and they may not reflect teachers' understanding of students' cognitive abilities	Assessments are relevant to the concepts being taught and reflect teachers' understanding of students' cognitive abilities	Assessments are relevant to the concepts being taught in full extent and reflect teachers' strong understanding of students' cognitive abilities		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Organize and manage student behavior	Teachers are less or not able to use rules, procedures to engage students learning; students misbehavior are ignored	Teachers are somewhat able to use rules, procedures to engage students learning; students misbehavior sometimes are ignored	Teachers are able to use rules, procedures to engage students learning; students misbehavior are corrected in a timely manner	Teachers use rules, procedures, and routines to ensure that students are actively involved in learning; students misbehavior are prevented		
	C) Class activities reflect an understanding of developmental theory of learning and how students learn	Learning activities are less or not appropriate to students' cognitive abilities and students are having hard time in learning	Learning activities are somewhat appropriate to students' cognitive abilities and students are learning in someway	Learning activities are appropriate to students' cognitive abilities and students are engaged in learning	Learning activities are appropriate to students' cognitive abilities and students are actively engaged in learning		
Technological Knowledge (TK)	A) Knowledge of the technology application	Teachers have less or no knowledge of the technology application used in teaching	Teachers somewhat understand the technology application used in teaching	Teachers have a sufficient knowledge of the technology application used in teaching	Teachers understand the technology application used in teaching proficiently		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Knowledge of operating particular technologies	Teachers are not able to use the technology application appropriately	Teachers are able to use the technology application with some degrees of difficulties	Teachers are able to use the technology application appropriately	Teachers are able to manipulate and use the technology application strategically		
	C) The ability to learn and adapt to new technology	Teachers show less or no ability to learn and adapt new technology and are not able to find solution when encounter technology issues	Teachers show somewhat ability to learn and adapt new technology and able to find solution with difficulty when encounter technology issues	Teachers show proficient ability to learn and adapt new technology and able to find solution when encounter technology issues	Teachers show strong ability to learn and adapt new technology and able to find solution quickly when encounter technology issues		

Technological Content Knowledge (TCK)	A) Link between technology and content is obvious or explicit	The technology choice not properly suits to contents and students may not be learning content objectives	The technology somewhat links to contents and it can be used in some ways to teach contents	The technology choice suit contents and it can be used to teach contents	The technology choice best address contents and it can be used in a variety of ways in teaching contents		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) An understanding of the representation of concepts using technologies	Teachers have less or no ability to use technology representations to help students to understand the concept	Teachers somewhat have the ability to use technology representations to help students to understand the concept	Teachers have the ability to use technology representations to help students to understand the concept	Teachers have strong ability to use technology representations to teach contents and understand the effect of technology on the concept		
	C) An understanding of the content can be changed by the application of technology	Teachers are not able to use the same technology to link between different contents or concepts	Teachers are somewhat able to use the same technology to link between different contents or concepts rarely provide examples	Teachers are able to use the same technology to link between different contents or concepts and provide examples	Teachers have a strong ability to use same technology to link between different contents or concepts and able to teach and provide examples of different contents		
Pedagogical Content Knowledge (PCK)	A) Demonstrates awareness of possible student misconceptions	Teachers hardly recognize student misconceptions	Teachers recognize student misconceptions and correct them when they occur	Teachers use casual questions and post questions to uncovering misconceptions and able to lead to conceptual change	Teachers use casual questions and post questions to uncovering misconceptions strategically and promote continual positive conceptual change		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Knowing how elements of the content can be arranged for better teaching	Teachers have less or no understanding of rearranging contents for better teaching	Teachers have some understanding of contents can be rearrange for better teaching	Teachers are able to rearrange the contents necessary based on class progress, students' cognitive ability, and their prior knowledge	Teachers have strong ability to rearrange the contents necessary based on class progress, students' cognitive ability, and their prior knowledge effectively		
	C) Knowledge of teaching strategies that incorporate appropriate conceptual representations of the content in order to	Teachers have less or no ability to use effective teaching strategy such as using manipulative to guide student thinking and learning, and	Teachers have somewhat ability to use effective teaching strategy such as using manipulative to guide student thinking and learning, and address learner	Teachers are able to use effective teaching strategy such as using manipulative to engage and guide student thinking and learning, and address learner	Teachers have strong ability to use effective teaching strategy such as using manipulative or pictorial representations to engage and guide student thinking and learning, address		

	guide student thinking and learning, and address learner difficulties and misconceptions.	address learner difficulty and misconnections	difficulty and misconnections	difficulty and misconnections	learner difficulty and misconnections		
Technological Pedagogical Knowledge (TPK)	A) Evidence of appropriate technologies enhancing student learning. Students use technology to explore content and achieve learning goals	Teachers have less or no ability to use strategies to engage and guide students explore and learning contents with technology	Teachers somewhat able to use strategies to engage and guide students explore and learning contents with technology	Teachers are able to use strategies to engage and guide students explore and learning contents with technology	Teachers have strong ability to use strategies to engage and guide students explore and learning contents with technology		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5) **Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	B) Knowledge of how technologies can be used to build on existing knowledge and to develop new ones or strengthen old ones.	Teachers do not demonstrate understanding of using appropriate sequence of technology applications and pedagogical methods to help students to learn new knowledge based on existing ones	Teachers have somewhat ability of using appropriate sequence of technology applications and pedagogical methods to help students to build new knowledge based on existing ones	Teachers demonstrate understanding of using appropriate sequence of technology applications and pedagogical methods to help students to learn new knowledge based on existing ones	Teachers have strong ability of effectively using appropriate sequence of technology applications and pedagogical methods to help students to build new knowledge based on existing ones		
	C) Knowledge of pedagogical strategies and the ability to apply those strategies for use of technologies	Teachers have less or no ability to use technology with appropriate pedagogical strategy in teaching	Teachers are somewhat able to use technology with appropriate pedagogical strategy in teaching	Teachers are able to use technology with appropriate pedagogical strategy in teaching	Teachers demonstrate strong ability to use technology with appropriate pedagogical strategy in teaching		
Technological Pedagogical and Content Knowledge (TPACK)	A) Appropriate technology enhances content objectives and instructional strategies	Teachers are not able to use appropriate technology enhance contents with appropriate teaching strategies	Teachers have somewhat ability to use appropriate technology enhances contents with appropriate teaching strategies	Teachers are able to use appropriate technology enhance contents with appropriate teaching strategies	Teachers demonstrate strong ability to use appropriate technology enhance contents with effective teaching strategies		**Weak** (111;121) (1 – 1.5) **Marginal** (122; 222; 223) (1.5 – 2.5)

	B) Demonstrate the knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face	Teachers have less or no knowledge of what makes concepts difficult or easy to learn and how technology can help	Teachers somewhat demonstrate knowledge of what makes concepts difficult or easy to learn and how technology can help	Teachers demonstrate knowledge of what makes concepts difficult or easy to learn and how technology can help	Teachers demonstrate strong knowledge of what makes concepts difficult or easy to learn and how technology can help		**Proficient** (233; 333; 334) (2.5 – 3.5) **Strong** (344; 444) (3.5 – 4)
	C) Pedagogical techniques that use technologies in constructive ways to teach content	Teachers are not able to use pedagogical techniques that use technology in constructive ways to teach contents	Teachers are somewhat able to use pedagogical techniques that use technology in constructive ways to teach contents	Teachers are able to use pedagogical techniques that use technology in constructive ways to teach contents	Teachers demonstrate strong ability of using pedagogical techniques that use technology in constructive ways to teach contents		

Appendix E

Division of Research Approval

UNIVERSITY of HOUSTON

DIVISION OF RESEARCH

June 10, 2014

Mr. Karman Kurban
c/o Dr. Jennifer Chauvot
Curriculum and Instruction

Dear Mr. Karman Kurban,

Based upon your request for exempt status, an administrative review of your research proposal entitled "Middle School Math and Science Teachers Perceptions of Their Growth in Technological Pedagogical Content Knowledge" was conducted on April 2, 2014.

At that time, your request for exemption under **Category 4** was approved pending modification of your proposed procedures/documents.

The changes you have made adequately respond to the identified contingencies. As long as you continue using procedures described in this project, you do not have to reapply for review. * Any modification of this approved protocol will require review and further approval. Please contact me to ascertain the appropriate mechanism.

If you have any questions, please contact Samoya Copeland at (713) 743-9534.

Sincerely yours,

Kirstin Rochford, MPH, CIP, CPIA
Director, Research Compliance

*Approvals for exempt protocols will be valid for 5 years beyond the approval date. Approval for this project will expire **June 9, 2019**. If the project is completed prior to this date, a final report should be filed to close the protocol. If the project will continue after this date, you will need to reapply for approval if you wish to avoid an interruption of your data collection.

Protocol Number: 14331-EX

316 E. Cullen Building Houston, TX 77204-2015 (713) 743-9204 Fax: (713) 743-9577
COMMITTEES FOR THE PROTECTION OF HUMAN SUBJECTS