IMPROVING THE IMPLEMENTATION OF TECHNOLOGY, TPACK, AND TEACHER SELF-EFFICACY WITHIN SECONDARY MATHEMATICS INSTRUCTION THROUGH TARGETED PROFESSIONAL DEVELOPMENT

A Record of Study

by

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ABSTRACT

Educational technology has the potential to be transformative in secondary mathematics classrooms. Recent events have further necessitated a paradigm shift in how technology is used. In this mixed methods action research study, I study the inputs to effective technology use and establish a combined model that shows their interaction with each other towards the output of effective technology use. I then explored professional development as a treatment designed to target and increase these inputs in teacher practice. The results indicate that focused PD was effective in increasing both teacher TPACK and self-efficacy with respect to technology. Further, the majority of teachers used technology at the levels of modification and redefinition on the SAMR (Substitution, Augmentation, Modification, Redefinition) scale. Findings support the use of focused PD as an intervention.

DEDICATION

I wish to dedicate this record of study to the many men and women who daily teach the beauty and wonder of mathematics. Though often neglected, forgotten, and discounted, you impact the future of humanity daily and make it an exponentially better and brighter future without limit.

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NOMENCLATURE

CAS	Computer algebra system
CK	Content knowledge
CRS	Classroom response system
DGS	Dynamic geometry software
ICT	Information and communication technology
PICRAT	Passive, Interactive, Creative, Replacement, Amplification, Transformation
PCK	Pedagogical content knowledge
PK	Pedagogical knowledge
RAT	Replacement, Amplification, Transformation
SAMR	Substitution, Augmentation, Modification, Replacement
TAM	Technology Acceptance Model
TCK	Technological content knowledge
TIM	Technology Integration Matrix
TK	Technological knowledge
TPK	Technological pedagogical knowledge
TPACK	Technological, pedagogical, and content knowledge

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INTRODUCTION: LEADERSHIP CONTEXT AND PURPOSE OF ACTION

The Context

The past several decades have brought to the forefront the need for infusing effective technology into educational classrooms. Mathematics educators have been at the center of this push, the trajectory of which suggests that ultimately, mathematics education will be thoroughly saturated by technology. The COVID-19 pandemic's disruption of normal K-12 education has only served to accelerate the progression of this trajectory. However, many secondary mathematics teachers still do not use technology as effectively as they could. One could view this goal of effective technology use in mathematics education classrooms as an output in a model with the inputs of teacher technological, pedagogical, and content knowledge (TPACK), self-efficacy, and perceptions of technology. The quality of these inputs can potentially be improved by using targeted professional development.

National and State Context

The larger picture of national and state contexts shows a clear need for mathematics teachers to be experts in teaching and facilitating learning with technology. A mathematics teacher's responsibilities for instruction and assessment have been substantially changed by the integration of technology.

Instruction in secondary schools was recently turned upside down by the COVID-19 crisis, which will continue to impact education globally for years to come. The pandemic forced teachers to become experts in virtual instruction. Alabdulaziz (2021) and others found that teachers felt the COVID-19 crisis had created an increased need to focus on technology; however, the digital revolution in mathematics education did not begin with the pandemic. The most recent position statement published by the National Council of Teachers of Mathematics (NCTM, 2011) championed the use of technology in the mathematics classroom as well. This statement emphasized the need for student learning to be transformed by technology and for teachers to be current in their knowledge of using technology within the mathematics classroom.

Assessment has been similarly transformed by technology, both nationally and at the state level. The SAT college admission test not only will be offered through online administration but will include the use of embedded tools such as the Desmos Graphing calculator (College Board, 2021). State assessments in Texas have followed a similar trend as the State of Texas Assessment of Academic Readiness (STAAR) assessment tests will now include embedded technology assets such as a TI graphing calculator and the Desmos Graphing utility (Texas Education Agency, 2021). This shift in test format and resources to the Desmos platform is substantial. Just a few years ago, Desmos was a technological accessory used for extension activities in the classroom. It has now become integrated into the core of mathematics education through these changes in assessment. The recent changes to the STAAR test also include new question types. Since the inception of the Algebra 1 STAAR test, only two question types, multiple choice and griddable, have been available. Now, the Algebra 1 STAAR test will include eight different types of questions (TEA, 2021). The additional six types can be implemented only through a digitally and virtually implemented assessment session. In short, assessments have become technologically enhanced in both focus and structure.

The implications of such changes to assessment processes are clear for teachers, who must prepare their students for success both in and outside the classroom. To do so properly, they must now contend with digitally driven instruction and assessment. To contend with this ongoing paradigm shift, teacher TPACK, perceptions of technology, and self-efficacy with respect to technology must be increased.

Situational Context

The school at the focus of this study was a 6A high school in southeast Texas with a student population of nearly 3,000 students. The school district covers an area of over 200 square miles and serves a total of over 26,000 students. The high school most recently had an overall accountability rating of B. It is a Title I school, with 61.7% of students classified as economically disadvantaged. The average SAT score for students attending this school was 998, and the average ACT score was 22.7. The three primary demographics of ethnicity are Hispanic/Latino (56.9%), White (35.4%), and African American (3.5%).

The high school's mathematics department contains between 20 and 25 teachers, in addition to special education co-teachers who assist in some classes. Due to recent turnovers in staffing, half of the mathematics teaching staff members were newly hired for the 2021–2022 school year, and one-third of the staff was composed of first-year teachers.

Instructional technology staffing at this high school is very limited. The librarian is often considered one of the primary sources of technology support. There is also one instructional technology specialist assigned to the high school. However, instructional technology specialists cover elementary and middle school campuses as well and are responsible for creating virtual trainings. The whole district has just three instructional technology specialists for more than 26,000 students. Thus, their actual impact on the individual classroom is minimal. Each department must take it upon itself to support teachers' technology needs in addition to their other responsibilities, as there is no clear support structure for teachers in terms of technology.

Although the school does not provide computers and calculators for each student's individual use, there are enough TI-Nspire calculators in each mathematics classroom to enable each student and teacher to have access to one during class sessions. A typical classroom has a smartboard-type device available for teachers to use, and the department has access to several carts of iPads and laptops. However, these are shared across the entire department. The only technology tools simultaneously available to all teachers are calculators.

On the software side of technology integration, a few web-based apps are used. One of the school's primary technology initiatives has been the use of Desmos as a primary asset in instruction and (only on a limited basis) in exploration. Another heavily used software application is iXL, a semi-adaptive practice application. Students are assigned a topic and complete problems at varying levels of difficulty, receiving a numerical score between 0 and 100. Finally, during the COVID-19 crisis, the district purchased Nearpod web-based software, which allows teachers to create virtual live and self-paced lessons with various types of formative assessments built in. However, Nearpod is rarely used in the math department.

Professional development (PD) initiatives have been limited in both the high school and district. Teachers are required to attend PD sessions at the beginning of the year and sporadically throughout the year. With the exception of a single district-wide teacher leadership academy initiative that ended in 2020, there have been no long-term PD initiatives in recent years. In the past, when such initiatives have been attempted, they were never completed, due to lack of teacher interest and administrative follow-through. PD targeted at technology has also been limited. Within the past decade, no long-term PD initiatives have targeted technology knowledge or use. PD sessions specific to technology have consisted only of short sessions on technical issues. For example, in the 2021–2022 school year, teachers were required to choose among four sessions offered throughout the year during their conference period. No session lasted more than 30 minutes, and each session was totally isolated from the others and focused only on basic mechanics of technology use. Similarly, some one-hour PD sessions have been offered during the summer, but they covered only the functional use of technology devices and platforms. Thus, the teachers at the high school are accustomed to short PD initiatives of limited scope.

The Problem

As I have worked with mathematics teachers at High School X, I have noticed and documented through conversations, requests for help, and observations that technology assets are not being effectively utilized to their fullest potential within mathematics instruction. While conducting extensive observations of classroom instruction during my internship it became evident that technological assets are typically used at the levels of substitution and augmentation as defined by the Substitution, Augmentation, Modification, and Replacement framework (Puentedura, 2003). Rarely did evidence of replacement and modification appear during instruction. Evidence of lower-level technology use primarily included using classroom technology for basic note presentations or basic computations. The typical apex of technology use involved graphing a function with technology to speed up the process or using iXL to remediate student understanding of math concepts.

Relevant History of the Problem

Historically, the use of technology in the mathematics department at this high school has been rather static. The current calculator model has been used in classrooms for seven years. Before that, the TI-84 was used in classrooms for over a decade. Various attempts have been made to increase the use of technology within the department. Seven years ago, three trainings were conducted on the SAMR model (described in chapter 2). Also, several directives have indicated the desired amount and frequency of use of technology assets. For example, during the 2021–2022 school year, teachers were asked to assign at least three iXL topics per week and to use Desmos once per week, although this directive was not consistently implemented. Other similar directives have sporadically been issued to teachers and within a few months, they often have been ignored. This inconsistent and ineffective use of technology within the classroom is one factor that drove the present study.

Significance of the Problem

The rapid increase of technology use in public schools has saturated the classroom with new devices and applications for instruction and assessment. Teachers are obligated to facilitate the mastery of content and the development of skills relevant to success in the world beyond the K-12 classroom. Great teachers have always embraced this task. In the past few decades, the burden has shifted to include a massive focus on technology. The history of technology within the context of mathematics education will be more robustly explored in Chapter 2. This shift has been part of society's broader progression toward becoming a technologically saturated culture, which experienced a forceful leap forward due to COVID-19 (Alabdulaziz, 2021). This new dynamic requires teachers to prepare students to use technology for both content-related and non-content-related concerns. The question today is not whether technology should be used but rather how teachers will integrate it effectively to equip students as self-sufficient problem solvers amidst the future's advanced challenges.

This dynamic also has its pitfalls and concerns. Technology can both transform and destroy learning. Teacher attitudes and concerns about technology will also be more closely examined in Chapter 2 and used as a part of a technology adoption model in Chapter 3. However, the main concerns center on uses of technology that diminish problem-solving skills and depth of understanding (Honey, 2018; Karadeniz & Thompson, 2018). Such concerns would center on technology use at the levels of substitution and augmentation in the SAMR framework (Puentedura, 2003) and replacement in the RAT framework (Hughes et al., 2006). Once again, technology will be used in the classroom; the question is how it will be used. Thus, the problem has significance on the macro level of mathematics instruction as a whole.

An additional factor demonstrating the significance of the problem to both the local and external contexts of mathematics instruction is the impact of technology on state and national assessments, which forces teachers to become technology leaders and experts. As noted above, the STAAR and SAT test formats and question types have been revised in new, high-tech ways (College Board, 2021; TEA, 2021). If these tests are used as measures of instructional effectiveness, then teachers must become champions of instruction that enables students to succeed on them.

This continuity of purpose and focus bridges the larger issue of technology use in mathematics education classrooms with the problem of practice facing the local context of mathematics instruction. The current context of the problem of practice and of this study included increased expectations for the use of certain technologies as expressed through district initiatives, the availability of devices, and the observed level of technology use as defined by the SAMR and RAT framework models (Hughes et al., 2006; Puentedura, 2003). Unquestionably, the problem of effective use of technology within mathematics classrooms has great significance both for the discipline as a whole and at this high school.

Research Questions

The purpose of this study was to explore how to increase the effectiveness of technology integration within secondary mathematics instruction at High School X. The experimental intervention consisted of PD sessions targeted to the teachers' needs in the areas of TPACK, self-efficacy with respect to technology, perceptions of technology, and practical implementation of technology. To determine the effectiveness of this approach, I answered the following research questions through my study:

1. What impact, if any, do focused technology-rich PD sessions have on improving mathematics teachers' self-perceptions of their TPACK, technology integration, and self-efficacy with respect to technology?
2. After attending focused technology-rich PD sessions, what evidence of TPACK and level of technology integration is observed during a technology-rich lesson?
3. After attending focused technology-rich PD sessions, how do the self-perceptions of teachers compare to what is observed during a technology-rich lesson?

Through this research, I assessed the viability of PD as a means of improving the effectiveness of technology use within secondary mathematics instruction at High School X.

Personal Context, Role, and History

My own experiences with technology and its far-reaching impact predate my entry into the education industry. Prior to becoming a teacher, I was a high-performing computing and tablet specialist for a Fortune 500 company. I also fulfilled contracting functions as a technology consultant for small businesses in the legal, nonprofit, and surveying industries. This experience led me to start my own small IT consulting firm.

From the inception of my career as an educator, I saw the latest technological advancements as doorways to greater learning. In almost 10 years as an educator, I have taught various levels, from grade 8 remediation to Advanced Placement statistics and dual credit/enrollment calculus. In each teaching situation, technology has been a vital part of my classroom.

In my role as an undergraduate and graduate-level faculty member, I have facilitated both mathematics and mathematics education coursework at multiple schools. Graduate-level courses have included mathematics education, pedagogy, curriculum and instruction, and online teaching. I was also privileged to serve as a subject-matter expert for a graduate program in online learning and subsequently taught courses on strategies for teaching K-12 online. My role with these organizations has also included helping to train faculty and staff in effective technology use. I have designed and implemented policies and PD intended to facilitate educators' growth in technology-enhanced learning, instruction, and assessment.

In each context where I have been privileged to teach, technology transformed my practice and classroom. Even before COVID-19 necessitated drastic measures, I utilized learning management systems such as Moodle and created bilingual instructional videos to flip instruction. I have always perceived technology as an educator's trusted friend. The operations of my classroom as they exist today would not be possible without the opportunities created by effective technology use.

Journey to the Problem

In the midst of my own instruction and journey with technology, I have also served as a technology mentor and advisor. Becoming known as a lover of technology results in many opportunities to assist others in their difficulties, both as a teacher and as team leader. I have become very familiar with the struggles that teachers of all ages and levels of experience face with technology. Along the way, I have gained extensive understanding of the gulf between technology's educational potential and how its use is actually enacted with classroom instruction.

My journey toward addressing this problem continued through my Ed.D. studies in Curriculum and Instruction at Texas A&M University. Through my initial coursework, I began to formulate a mindset of research-based change. My internship also helped me grasp this problem of practice, as I was able to observe every type of mathematics instruction that takes place on my high school campus over the course of several months through the lens of several existing technology integration frameworks, which I will discuss later in this study. During the internship, I also discussed perspectives on technology with classroom teachers, mathematics teacher leaders, and campus administrators. The observations provided me valuable insights into the problem, while the discussions themselves allowed me to hear the voice of those most acquainted with the challenges of technology use in mathematics education classrooms.

Significant Stakeholders

The primary stakeholders of this study were the mathematics teachers at High School X, because they are the people who integrate technology into instruction and design lessons. This group included both classroom teachers and the department's instructional leaders, such as team leaders, the department chair, and the instructional coach. These individuals all teach classes within the department in addition to holding leadership roles. This study focused on teachers' different types of knowledge, use of technology, perceptions, and self-efficacy toward technology.

A second important group of stakeholders was the student population of the high school. Every student in Texas must take three or four years of high school mathematics. Thus, each student will be impacted by the improvements this study could deliver by improving technology integration in the classroom. Other stakeholders include campus administrator, district administrators, district curriculum support staff, families of students, and the community. Each of these stakeholder groups benefits in some way from increased effectiveness of technology integration within mathematics classes.

Important Terms

Amplification: The middle level of the RAT framework or model. At this level, technology use is equal to the level of replacement but with noticeable functional improvement (Hughes et al., 2006).

Augmentation: The second level of the SAMR framework or model. At this level, technology allows for substitution that involves functional improvements that can be noticed but are not necessarily significant (Puentedura, 2003).

Computer algebra system (CAS): A computer utility or device that allows rapid analysis of problems with significant depth and advanced detail. CASs can be integrated into a handheld calculator unit. Examples include the TI-NSpire CX CAS and TI-89 calculators. CASs can also be web-based applications, such as Wolfram Alpha and Symbolab.

Content knowledge (CK): The knowledge that teachers have regarding their specific content area (Shulman, 1986).

Classroom response system (CRS): Software or devices that enable synchronous or asynchronous responses by participants as a means of communication or assessment. Current examples include iClickers, Nearpod, and response pads.

Creative: The highest level of the second domain of the PICRAT model. At this level, the dynamic of the lesson is student-driven in that students create using technology (Kimmons et al., 2020).

Dynamic geometry software (DGS): Software that allows the creation, visualization, and manipulation of geometric shapes, objects, and models. Current examples include Desmos Geometry and GeoGebra.

Information and communication technology (ICT): Technology that can be used to facilitate the collaboration of ideas and information among students during learning

Interactive: The middle level of the second domain of the PICRAT model. At this level, the students interact significantly with technology (Kimmons et al., 2020).

Passive: The lowest level of the second domain of the PICRAT model. At this level, the student relationship to technology in the classroom is passive in that students receive instruction or knowledge through technology but do not interact with it to solve problems or exhibit critical thinking in more robust problem-solving. (Kimmons et al., 2020).

Passive, Interactive, Creative, Replacement, Amplification, Transformation (PICRAT): A technology model or framework that built on the RAT framework by adding a second dimension containing passive, interactive, and creative aspects of technology use, based on a student-centered perspective (Kimmons et al., 2020).

Pedagogical content knowledge (PCK): The convergence of pedagogical and content knowledges to create a knowledge type in which teachers are aware of the methods and strategies specific to a unique content area (Shulman, 1986).

Pedagogical knowledge (PK) – Teachers' knowledge about methods, strategies, and approaches to teaching in general (Shulman, 1986). It is not specific to content or technology.

Redefinition: The highest level of the SAMR model. At this level, technology redefines what is possible by offering choices for instruction and learning that would otherwise be impossible without the use of technology (Puentedura, 2003).

Replacement: The lowest level of the RAT model. At this level, technology replaces a nontechnology method or function, but with no functional improvement (Hughes et al., 2006).

Replacement, Amplification, Transformation (RAT): A technology model or framework that defines technology use at one of three levels (Hughes et al., 2006). (The three terms designating the levels are defined elsewhere in this section.)

Substitution, Augmentation, Modification, Replacement (SAMR): A technology model or framework that defines technology use at one of four levels (Puentedura, 2003). (The four terms designating the levels are defined elsewhere in this section.)

Substitution: The lowest level of the SAMR model, in which technology is used in a way that substitutes for nontechnology tasks but with no improvement in function or efficiency (Puentedura, 2003).

Technology Acceptance Model (TAM): A model of user acceptance of technology in which the influences affecting technology acceptance are examined as inputs (Davis, 1985).

Transformation: The highest level of the RAT model or framework, in which technology transforms learning into something that would not otherwise be possible without its use (Hughes et al., 2006).

Technological content knowledge (TCK): This is the convergence of content and technology knowledges, or specifically knowledge of how to use technology to teach specific content (Kohler & Mishra, 2009).

Technology Integration Matrix (TIM): A model of technology integration that scores five individual categories on a scale of entry, adoption, adaptation, infusion, and transformation (Harnes et al., 2016).

Technological knowledge (TK): General knowledge of technology, not specific to content or pedagogy (Kohler & Mishra, 2009).

Technological pedagogical knowledge (TPK): The convergence of technological and pedagogical knowledges (Kohler & Mishra, 2009), or knowledge of how to teach with technology.

Technological, pedagogical, and content knowledge (TPACK): The ultimate convergence of the domains of knowledge about technology, pedagogy, and content (Kohler & Mishra, 2009). This domain encompasses what teachers know about how to teach their specific content using technology and instructional strategies that are specific to technology.

Closing Thoughts on Chapter 1

Effective technology integration and use has the potential to both transform and inhibit learning in mathematics education. The current trajectory within mathematics education presages a continued increase of technology integration, which is ultimately destined to permeate every facet of mathematics instruction. To properly serve students, teachers must become technology champions. This can be accomplished only when teachers are equipped with the knowledge they need to increase effective technology use and improve their self-efficacy and perceptions of technology.

In this mixed-methods action research study, I investigated the use of targeted PD as an intervention to increase the effectiveness of classroom technology integration within mathematics education classrooms at High School X by targeting teacher TPACK, self-efficacy, and level of technology use. I developed and measured the impact of focused PD sessions based on known needs. I assessed the effectiveness of this approach by collecting quantitative data through pretests and posttests and qualitative data through observations. I analyzed these data qualitatively, quantitatively, and through using a mixed methods approach.

In Chapter 2, I examined the historical context of using technology in mathematics instruction and inputs to the problem of practice. I then presented the detailed methodology in Chapter 3, the analysis and results in Chapter 4, and my conclusions in Chapter 5.

CHAPTER II LITERATURE REVIEW

Introduction

The use of technology has continued to increase within the field of mathematics education. Technology use has always been a part of effective mathematics instruction. Yet, the necessity of technology use has been accelerated in recent years. Alabdulaziz (2021) found that teachers felt that the COVID-19 crisis has resulted in an increased need for a focus on technology. New technology focuses emerged during virtual instruction implementation that have changed how we teach students math. Assessment has also taken on a paradigm shift sparked by the digital revolution. Targeted technology changes have revised the state assessments of mathematics in Texas. Instead of only allowing multiple choice and grid response questions on assessments, a total of eight different question types will now be used for testing mathematics (TEA, 2021). Implementing these types of questions is only made possible by advances in technology. State testing will also be completely online by the year 2022 (TEA, 2021). This evidence clearly points to an inescapable conclusion: Mathematics teachers must be leaders in technology! Despite this inevitability the problem remains that mathematics teachers are not effectively using technology within instruction. To understand the nature of the successful integration of technology within the content of mathematics education, one must first understand the various topics that provide an input to the problem of practice.

Throughout Chapter I established a foundation for the problem of practice through its historical, theoretical, and practical inputs and present a possible solution. I will begin with an examination of the broad history of technology and its historical use within mathematics education classrooms. This history will enable us to understand the timelessness of the problem. Next, I will discuss the different types of teacher knowledges and their intersections and examine the current technology frameworks that provide lenses for understanding how technology can be implemented within mathematics classrooms. Teacher knowledge types and technology frameworks form the two theoretical inputs to the problem of practice. Once this historical foundation and theory is laid, I will explore the types of technology that are frequently used within mathematics education classrooms today and discuss the intricacies of teacher perceptions that impact technology integration and implementation. These two components establish the practical inputs and current context of what technology looks like and how math teachers interact with technology. Finally, we will conclude with an exploration of using professional development as an intervention to solve the problem of practice.

The History of Technology within Mathematics Education

The use of technology has been a consistently maintained best practice within mathematics pedagogy. The National Council of Teachers of Mathematics (NCTM) has held the use of technology in high regard as long as it has been publishing recommendations. Its 1980 *Agenda for Action* stated that “mathematics programs must take full advantage of the power of calculators and computers at all grade levels” (p. 8). In 1989, NCTM published its first set of national content standards—in fact, the first such set of standards in any discipline in the United States. This publication had a major influence on the whole field of education and helped to give birth to the standards-based education movement (Dawson, 2010). NCTM’s 1989 standards document stated clearly that one underlying assumption was the availability of relevant technology for use within the classroom. These standards have served as the foundation for all subsequent mathematics standards at the state and national levels. Accordingly, it would seem safe to assume the mathematics content standards developed over the past four decades similarly presume and necessitate the inclusion of relevant technologies.

To understand the history of technology implementation in mathematics education it is necessary to first understand what constitutes technology. In addition to providing a robust three-part definition of technology that encompasses purpose, function, and benefit, Carroll (2017) described technology generally as “something created through ordering exhibiting organization whose aspects function with a purpose that can provide some benefit” (p. 18). Based on this broad definition, technologies include any methods and tools created by humans to address problems scientifically. This indicates that the use of technology in the teaching and learning of mathematics was not a new concept in 1980 when NCTM published its *Agenda for Action* document. Rather, technology applications precede the advent of the digital technologies with which we are familiar today. If we accept this definition, then our review of technology use in mathematics education must go back before the advent of the calculator and other digital technologies.

In one much earlier example of technology application, Horton (1937) recommended that calculating machines be examined by every mathematics teacher. Horton further stated that teachers should be “equipping the student with every possible device to cope with the present trend in complicated educational and commercial figuring” (p. 271). This is perhaps the earliest reference within academic literature proposing the use of computational technology within mathematics education. This trend continued to develop in the years to come. Schaughency (1955) examined the use of computing machines in the context of an elementary mathematics classroom. Schaughency highlighted the potential role of technology in fostering student engagement and satisfaction, a concern that remains prominent today. Schaughency reported finding great enthusiasm among students and that math had taken on a new degree of interest for them. Hoffman (1965) extended this inquiry to the secondary level, stating, “It is only a matter of time for this to become common and, indeed, standard practice" (p. 400). This establishes a clear trend in which technology use is a priority in mathematics pedagogy.

As long as there has been literature available on the topic, technology use within the context of mathematics education has been considered a research-based best practice. For over 80 years, researchers have suggested using computational technologies within mathematics education. This trend has withstood the test of time and fluctuating perspectives on mathematics education theory and practice. During this more than 80-year time frame, multiple major national reforms occurred in mathematics education, including the Activity (Kilpatrick, 1934), Life-Adjustment (Klein, 2003; Loss, 2010; McFarland, 1954), New Math (Bybee, 1997; Phillips, 2014), Back to the Basics (Romberg, 2010; Stengle, 2010), Standards-Based (Dawson, 2010; Klein, 2003), and Common Core (Karp, 2014) movements. Yet the use of technology has remained a consistent best practice that has transcended each movement.

Alignment with Action Research Traditions

Professional Development as an Intervention

Professional development could facilitate the increase of TPACK, teacher self-efficacy, and overall teaching success. Loucks-Horsley et al. (2010) examined how professional development could be designed to initiate change in mathematics and science education. Their study supported the use of professional development to address issues in teacher knowledge. They emphasized that teachers must have knowledge of both the curriculum and pedagogy to implement change in the classroom. Loucks-Horsley et al. recommended immersion in the instructional content and processes to increase knowledge.

Other studies have also supported professional development as an intervention to enhance teacher knowledge and pedagogy. For example, Gómez-Blancarte and Miranda (2021) recommended using professional development through a bridge created by participation and reification to connect the practice of mathematics teaching to mathematics education research. Driskell et al. (2018) tied the use of professional development in mathematics education to the aspects of TPACK (Koheler & Mishra, 2009) and the Comprehensive Framework for Teacher Knowledge (CFTK; Ronau & Rakes, 2012). Once again, the use of professional development to increase TPACK and other knowledge types is inseparable.

Attributes of Effective Professional Development

What constitutes effective PD? This question has been debated over many years. Sims and Fletcher-Wood (2021) argued that agreement on the precise nature of effective PD has not been completely reached. However, they did identify multiple attributes that have gained broad consensus support and have been incorporated into government policies and publications in various countries. One such recent publication that has provided guidance for PD is the Learning Policy Institute report called *Effective Teacher Professional Development* (Darling-Hammond et al., 2017) This report has been cited approvingly in multiple studies (Bates & Morgan, 2018; Lo, 2021). The basic attributes of effective teacher PD have been described as "(a) content focus; (b) use of models and modeling; (c) active learning; (d) collaboration; (e) coaching and expert support; (f) feedback and reflection; and (g) sustained duration" (Lo, 2021, p. 138).

Other authors have proposed similar guidelines. For example, Liao et al. (2017) examined the changes in the perceptions of teachers about technology PD over a six-year period. They found that teachers valued a workshop structure, hands-on opportunities, and teacher-led PD. Teachers also expressed a desire for the opportunity to "go beyond learning how to use technology tools in order to gain pedagogy-related knowledge on how to integrate these tools in their curriculum" (Liao et al., 2017, p. 533). The results of this study indicated that teachers strongly preferred technology PD specific to their context and needs. The same emphasis emerged from a meta-analysis of published studies on technology PD conducted by Avci et al. (2019). They found that effective technology PD had a learner-centered focus.

Finally, effective PD includes both active learning and collaboration. Avci et al. (2019) integrated these two emphases into a single theme, whereas other researchers (Bates & Morgan, 2018; Darling-Hammond et al., 2017; Lo, 2021) identified these as two separate aspects of good PD. Bates and Morgan (2018) noted the similarities between active learning in teacher PD and inquiry-based learning.

Theoretical and Conceptual Frameworks

Teachers' Knowledge Types and Their Intersections

One of the primary contributors to classroom success is the knowledge that teachers bring to the table. Researchers such as Shulman (1986) and Kohler and Mishra (2009) have suggested various types of teacher knowledge that contribute to teacher success and the specific knowledge types that are created by their intersections. These include content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK). Each of these is distinct from the others, and all of them inform a teacher's practice within the classroom. Therefore, it is necessary to explore each type of knowledge and their convergences in the context of their application to mathematics teaching and learning.

Content Knowledge

CK refers to teachers' knowledge about their specific subjects (Shulman, 1986). Multiple researchers have found that CK tends to vary depending on the level of instruction. For example, elementary teachers are often low in CK because they are trained to address multiple subject content areas at the same time. Conversely, secondary teachers usually have greater CK because their certifications are specifically tied to their knowledge of a specific core subject such as mathematics.

Pedagogical Knowledge

PK refers to teachers' knowledge about the methods of teaching (Shulman, 1986). Pedagogy deals with the methods of instruction. One might call this the how of teaching. There are some fundamental knowledge types within this heading that would apply universally, such as how to apply learning theory and general instructional strategies. This level of knowledge is not content-specific. Instead, it entails the knowledge that all teachers should have regarding instruction in general (Shulman, 1986).

Technological Knowledge

TK refers to teachers' knowledge of technology (Kohler & Mishra, 2009). This level of knowledge is not specific in its application to content or pedagogy. TK would include the basic understanding of the broad use of technology and how to troubleshoot with that technology. The types of technology contained within this domain of knowledge could include both content-specific ones and those that impact multiple content areas.

Pedagogical Content Knowledge

PCK refers to what teachers know about how to teach their respective content. The applications of PCK are specific to a content field. Shulman (1986) stated that they "include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Examples of PCK could include English teachers' understanding of how to teach sentence diagramming or mathematics teachers' understanding of how to teach graphing. Specifically, this knowledge type applies broad pedagogical practices to the instruction of an individual content area. Such strategies will thus often be specific to the particular content taught, or to the domain of content covered at a given grade level.

PCK can intersect with the broader form of pedagogical knowledge. For example, one broad form of PK related to an instructional strategy may be the use of journaling in instruction. At the level of PCK, this application could be further refined to address the specific nuances of journaling within the content domain that students would examine. For example, students may write about their observations related to the mathematical concept of slope. PCK will also allow answer the question of how to teach without technology as a focused consideration. For example, a seasoned teacher may choose to execute a lesson through using effective questioning as an instructional strategy. This is certainly a research-based best practice that enriches and enhances instruction. However, it does not involve technology.

Technological Pedagogical Knowledge

TPK refers to what teachers know about teaching with technology. According to Kohler and Mishra (2009), "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" (p. 1028). TPK ignores the context of content and instead focuses solely on the broader application of pedagogy using technology, or what teachers know about how to teach using technology.

TPK, of course, has various applications within the different technology integration and implementation frameworks. An application could be as simple as using technology to perform the a task that could be done similarly without the use of technology, or it could involve using technology to elevate instruction to a level that was not previously possible without the use of that technology. Examples of such technologies range from using cloud-based office software for document preparation and class presentations to basic calculator use.

Technological Content Knowledge

TCK refers to what teachers know about how their content intersects with technology (Kohler & Mishra, 2009). TCK focuses on the convergence of content and technology. Here the concern is not for how the content is taught but for the ways in which technology can augment, replace, or transform the content itself. One example within the context of mathematics education could be the use of a computer algebra system or a graphing calculator. These are technologies that directly relate to the context of mathematics. Other such examples could include dynamic geometry software such as Desmos Geometry and GeoGebra. In their seminal work on the topic, Kohler and Mishra (2009) specifically defined an example of TCK as the way in which dynamic geometry software programs could change "the nature of learning geometry itself" through " a form of representation in mathematics that was not available prior to this technology" (p. 1028). This further confirms the current relevance of TCK, given that dynamic geometry software programs like Desmos Geometry and GeoGebra are still prevalent today.

Technological, Pedagogical, and Content Knowledge

Finally, TPACK refers to the convergence of TK, PK, and CK. Kohler and Mishra (2009) stated:

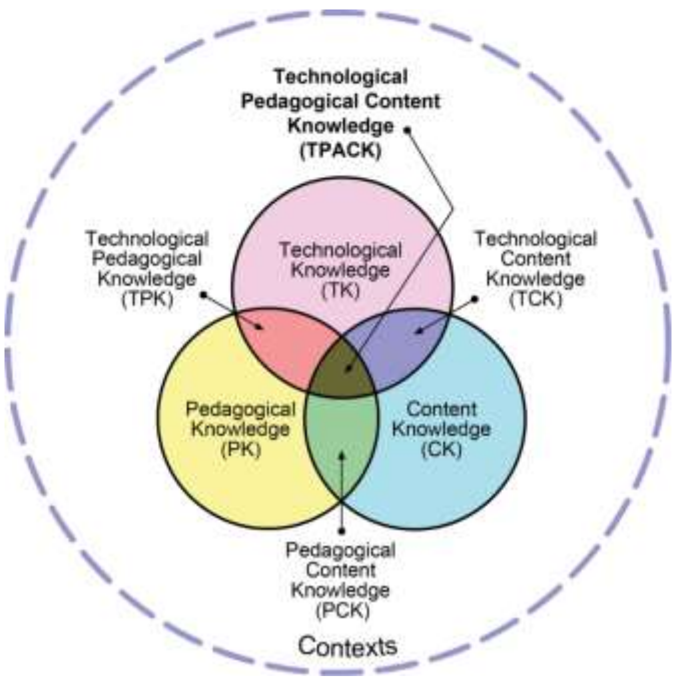
> TPACK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts

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)

TPACK embodies the culmination of what a teacher knows about teaching content with technology, as shown in Figure 1.

Figure 1

TPACK Diagram (Kohler & Mishra, 2009)



This focus answers the question of what teachers know about methods and strategies for teaching their specific content with technology (Kohler & Mishra, 2009). This is the most contextually specific focus of teacher knowledge as it relates to technology, pedagogy, and content. This domain seeks to contextualize knowledge with the highly specific, content-focused pedagogy and content-focused technology as well.

Current Technology Frameworks

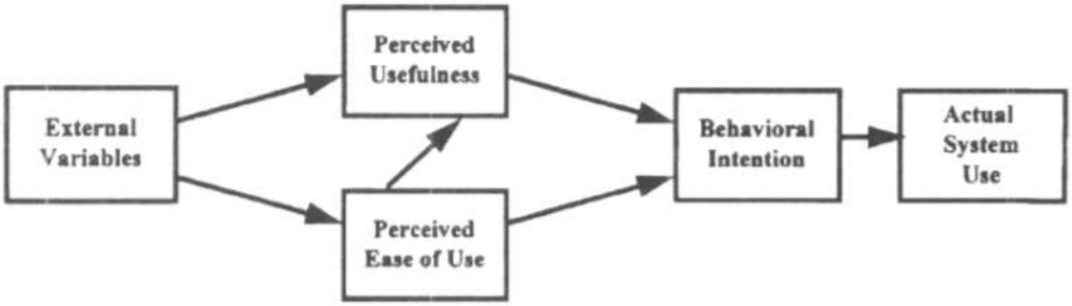
Several technology frameworks are currently considered best practices within the field of education. Such frameworks are important for understanding how to effectively integrate technology within instruction. Each framework provides a different clue toward understanding the implementation of technology within the classroom on a more holistic level. The frameworks relevant to the current context of the problem of practice include the Technology Acceptance Model (TAM; Davis, 1985), Substitution, Augmentation, Modification, Replacement (SAMR; Puentedura, 2003), Replacement, Amplification, Transformation (RAT; Hughes et al., 2006), the Technology Integration Matrix (TIM; Harnes et al., 2016), and Passive, Interactive, Creative, Replacement, Amplification, Transformation (PICRAT; Kimmons et al., 2020).

The Technology Acceptance Model

The TAM (Davis, 1985; Venkatesh & Davis, 1996) was first proposed to judge how technology would be accepted by users. The TAM encompasses three primary factors: perceived ease of use, perceived usefulness, and attitude toward using the technology (Davis, 1985). Attitude was subsequently replaced with behavioral intention (Venkatesh & Davis, 1996). The aspects of perceived ease of use and perceived usefulness are also said to be influenced by external factors (Chuttur, 2009). Figure 2 presents a diagram of the TAM.

Figure 2

The Technology Acceptance Model (Venkatesh & Davis, 1996)



Although it is a relatively old model, the TAM still has potential relevance today. An example of this can be seen in a study conducted by Karedeniz and Thompson (2018) who stated that "teachers' pedagogical perspectives had a major influence on how they chose to use the technology within their instructional practice, despite any intentions of technology developers" (p. 3). Since these perspectives could influence teachers' perceptions as to the ease of using technology and its usefulness, it is logical to assume that the TAM can be coupled with other models to measure how teachers accept and integrate technology within their classrooms.

Substitution, Augmentation, Modification, Redefinition

The SAMR framework (Puentedura, 2003) was first presented as an applied best practice; research on its use has since been extended. The original study of the SAMR framework used in as one of three axes in a three-dimensional model for assessing network-enhanced courses, along with the ephemerality and social domain perspectives. Since then, SAMR has been deployed to assess technology usage in general.

The name SAMR contains the four levels that make up this framework. Substitution refers to a simple switch from other methods to technology with no functional improvement (Puentedura, 2003). Augmentation differs from substitution only in that there exists a functional improvement in the use of technology (Puentedura, 2003). Modification signifies the use of technology in a way that "allows for the redesign of significant portions" (Puentedura, 2003, p.

3) of the learning process. Finally, at the redefinition level, technology is used to create a learning experience so substantially different from the existing methods that it would not be possible without the use of that technology. This is the peak of the SAMR framework.

Replacement, Amplification, Transformation

The Replacement, Amplification, Transformation (RAT) framework (Hughes et al., 2006) is a simplification of the SAMR framework. The authors defined replacement level by stating, "The Technology as Replacement category involves technology used to replace and in no way change established instructional practices, student learning processes, or content goals" (Hughes et al., 2006, p. 1617). This is the most basic form of technology use in the classroom. Examples within the context of mathematics education could include using a document camera for the conventional delivery of notes through direct instruction. The authors defined the second category as follows: "The Technology as Amplification category focuses on technology use that amplifies current instructional practices, student learning, or content goals" (Hughes et al., 2006, p. 1617). Teaching at this level would be possible but not as good without technology. Examples could include graphing logarithmic functions with a graphing utility or the use of digital note binders. In each case, the task would be completely possible without technology, but the technology application enhances speed and efficiency. Finally, "The Technology as Transformation category involves technology use that transforms the instructional method, the students' learning processes, and/or the actual subject matter" (Hughes et al., 2006, p. 1618). The transformation level would be similar to redefinition in the SAMR framework presented by Puentedura (2003). It is perhaps not frequently observed in instruction. However, as technology use continues to grow, new applications that can facilitate transformation are becoming available. Examples include the ways in which dynamic geometry software, TI-Nspire rover programming, and other applications can facilitate learning and exploration tasks in ways that would be otherwise impossible.

The Technology Integration Matrix

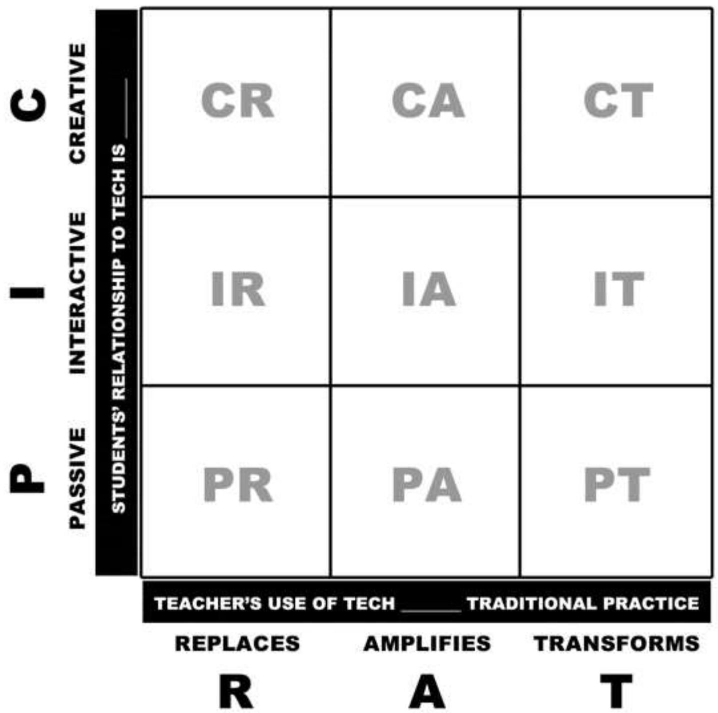
The TIM (Harnes et al., 2016) is a technology integration framework that categorizes the use of technology in the classroom based on its implementation and how students and teachers interact with it. The matrix itself is more of a rubric that provides different levels horizontally for each of the primary categories. It contains five levels: entry, adoption, adaptation, infusion, and transformation (Harnes et al., 2016). These levels are based fundamentally on the level of control that students and teachers have in the learning experience. The vertical axis focuses on the types of activities and learning that are taking place within the classroom. However, the control aspects is probably of greatest interest in this framework. Given the current push toward learning and teaching methods that prioritize a student-centered and teacher-facilitated approach (NCTM, 2014) this framework would help to prioritize the evaluation of best practices within that specialized context.

Passive, Interactive, Creative, Replacement, Amplification, Transformation

The Passive, Interactive, Creative, Replacement, Amplification, Transformation (PICRAT) framework for technology integration builds on the RAT framework by including a measure of student integration. Its developers stated, “We emphasize three basic student roles in using technology: passive learning (receiving content passively), interactive learning (interacting with content and/or other learners), and creative learning (constructing knowledge via the construction of artifacts)” (Kimmons et al., 2020, p. 185). Figure 3 presents a diagram of the PICRAT matrix.

Figure 3

The PICRAT Matrix (Kimmons et al., 2020)



The PICRAT model creates a type of bivariate consideration that correlates the level of student use with the level of technological integration. The determination of the level of RAT is based on two fundamental questions: "Are the achieved learning outcomes of the activity clearly better than they would have been without the technological or via a lower tech solution?" and "Could the activity have reasonably been done without the technology or via a lower tech solution?" (Kimmons et al., 2020, p. 189). Answering no to the first question results in a level of replacement. Answering yes to the first question and no to the second question results in amplification. Answering no to both questions results in a level of transformation. The authors defined examples of the creative level as student-created presentations, video documentaries, and journaling.

Most Significant Research and Practice Studies

Types of Technology Frequently Used in Mathematics Education

Various technology assets are available to classroom teachers today, and they serve a variety of purposes. Some have specific applications to mathematics, whereas others have broader applications. The most common technology tools relevant to secondary mathematics education today include graphing calculators and utilities, computer algebra systems (CAS), dynamic geometry software, classroom response systems (CRS), technology-based games, and tools for facilitating collaboration and communication.

Graphing Calculators and Utilities

Graphing calculators and utilities are among the most prevalent technologies used within the mathematics education classroom today. They initially came on the scene under the name of microcomputers (Demana & Waits, 1987). The use of these devices has been supported numerous times by research. For example, Kandemier and Demirbag-Keskin (2019) found that using graphing calculators improved student perceptions of mathematics and made their learning more enjoyable. Parrot and Leong (2018) found that using graphing technology provided benefits in the area of problem-solving. Lyublinbskaya and Tournaki (2011) reported a significant improvement in test scores by most students when the TI-Nspire was used.

Computer Algebra Systems

Alabdulaziz (2021) found that CASs were among the technologies receiving increased use during the COVID-19 crisis. These technologies can be either web-based or built into handheld calculator devices. Laumakis and Herman (2018) examined the differences in the uses of the TI-89 and TI-Nspire CAS calculators. They found an overall improvement in outcomes when either CAS calculator was used. CAS calculators and utilities have a primary benefit in the bulk of calculations that they can assume. For example, Mohammad (2019) found that students preferred to use the CAS when they perceived that the problem they were working on would take a long period of time to solve. Other studies have demonstrated improvements in learning due to the use of CAS devices including problem solving, visualization improvements, and enhancements of spatial skills (Karakus & Aydin, 2017; Mohammad, 2019; Şimşek & Ipek, 2019).

Dynamic Geometry Software

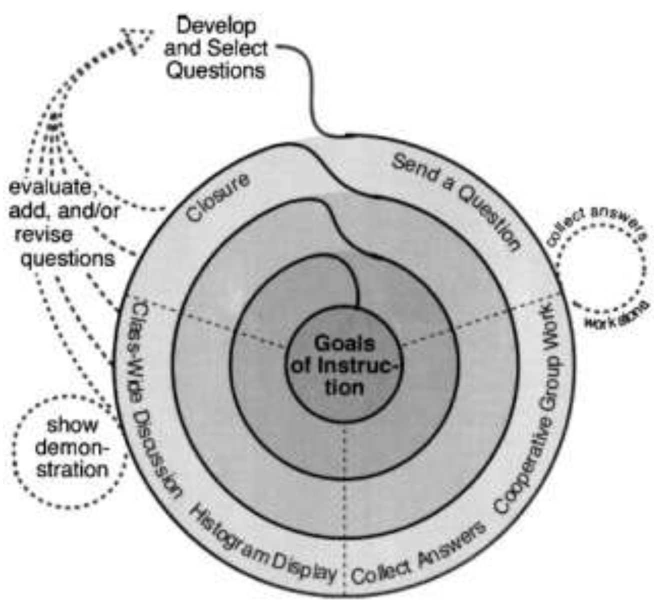
Dynamic geometry software (DGS) allows students to visually examine, manipulate, represent, and measure geometric relationships. One of the first examples of a DGS was the Geometer's Sketchpad, developed under a partnership with the National Science Foundation (NSF; Scher, 1999). Other examples currently in use include Desmos Geometry and GeoGebra. Multiple studies have associated the use of such software platforms with student success. For example, Ganesan and Kwan (2020) found that the Geometer's Sketchpad improved student learning about circles and received positive feedback from students. Alabdulaziz et al., (2021) examined the GeoGebra platform during the instruction of polar coordinates and complex numbers and found that students who used this tool had higher achievement scores and longer learning impact than those who did not.

Classroom Response Systems

Classroom response systems (CRSs) allow for a highly interactive classroom. These devices allow the facilitator to engage in real-time response and communication with students. Such a technology has the power to transform instruction. For example, Morais et al. (2015) examined the use of a CRS during a mathematics lesson in conjunction with problem-based learning (PBL). They confirmed the benefits of the enhanced level of communication established between the teacher and students. They also commented on the improved working atmosphere and suggested that such technology should be implemented beyond the scope of mathematics education, so as to enable real-time assessment to take place. Building on works by Dufresne et al. (1996) and Beatty et al. (2006), Mu'alimin (2019) examined the use of a CRS called Plickrs during mathematics instruction. The findings supported the use of CRS in mathematics education and built on the cycle of questioning proposed by Dufresne et al. (1996), as indicated in Figure 4.

Figure 4

Cycle of Questioning Used for Question-Driven Instruction with a CRS (Mu'alimin, 2019)



Technology-Based Games

Technology-based games allow for an engagement factor that may not otherwise be available. Gamification has been suggested as a means of increasing student successes in math classes. However, the research on game-based learning in mathematics is somewhat shaky at present. A meta-analysis by Tokac et al. (2018) found some benefits but indicated that more research was needed. However, some studies (Moon & Ke, 2020; Plass-Nielsen & Wolter Nielsen, 2019) have indicated possible gains in achievement and engagement.

Tools for Facilitating Collaboration and Communication

Alabdulaziz (2021) noted that one of the key applications of technology observed by teachers during the COVID-19 crisis involved greater use of information and communication technologies (ICTs) to facilitate communication. Communication and collaboration are key components of successful mathematics education. Indeed, NCTM (2000) has created a process standard focused specifically on communication and has reinforced this emphasis in its "Principles to Action" publication (NCTM, 2014). NCTM has also published multiple resources on practices related to increasing communication, discourse, and discussion (Stein & Smith, 2018). Thus, the use of communication and collaboration software supports current best-practice trends. This trend received further support from a research review by Verschaffel et al. (2019), in which every study examined supported the claim that ICT use improves both learning and metacognitive learning.

Teacher Perceptions of Technology Integration and Implementation

Teacher perspectives and attitudes are a crucial element in the use and implementation of technology in the classroom, consistent with the TAM framework (Davis, 1985). Each of the three factors in the TAM—perceived ease of use, perceived usefulness, and attitudes toward technology—relates directly to the teacher's function as an input to how technology would be influenced and perceived in the model. For example, Honey (2018) noted, "Teachers who value by-hand calculations will prefer pen-paper working, whereas teachers who think that multiple representations are a key feature of relational understanding are more likely to include graphic calculators for demonstrating different representations" (p. 12). Examining precalculus teachers' perceptions and use of technology, Karadeniz and Thompson (2018) stated that teachers' opinions about how content should be best instructed played a substantial role in how the teachers implemented technology in their classrooms. Teachers therefore become the primary pivot point that determines the course and direction of technology use in the mathematics education classroom. Key aspects that influence teachers' use and acceptance of technology in mathematics education include self-efficacy, attitudes of opposition or concern, and attitudes in favor of adoption and integration.

Teacher Self-Efficacy

Self-efficacy refers to individuals' perception of their own ability to successfully achieve certain results (Bandura, 1977). Within the context of the present discussion, a teacher's self-efficacy with respect to technology usage within mathematics education would refer to the teacher's own perception or belief as to how capable they are of implementing technology within their own instruction. This perception relates directly to the area of TPACK. Bakar et al. (2020) found that "mathematics teachers' self-efficacy of technology integration and TPACK were strongly associated" (p. 259). This correlation was said to be higher than other factors like gender and teaching experience. These results were consistent with those of multiple other studies such as Abbitt (2011), Kazu and Erten (2014), and Semiz and Ince (2012). As teachers' knowledge of technology and TPACK increases, their self-efficacy with respect to the use of technology in teaching and learning is also directly impacted. These findings offer a possible solution to the problem of supporting mathematics teachers in their classroom use of technology.

Teacher Attitudes of Opposition and Concern

One of the primary barriers in implementing technology in the mathematics classroom involves teachers' opposition to the use of technology. For example, Demana and Waits (1987) expressed initial concerns when graphing calculators, then called microcomputers, initially were entering classroom instruction. Specifically, they worried that the use of the graphing utility itself would not be enough as a primary means of graphing. While examining the potential associations between the ways in which graphing technology was used in high school and how students performed subsequently in a college calculus course, Mao et al. (2017) reinforced these concerns. After analyzing data collected through surveys of 7,087 students in 134 colleges and universities, Mao et al. stated that "extensive calculator use in high school was negatively related to students' later performance in college calculus, while putting restrictions on calculator use was positively related" (p. 81). Despite this finding, Mao et al. still supported the use of graphing technology, noting that it maintained a positive impact "if [the students] had used calculators in high school in certain restricted ways that had subordinated calculator use to, and combined it with, other techniques" (p. 81). The evidence presented here suggests that legitimate opposition to the use of technology lies not in its overall use but in how it is used.

This view was further confirmed by Karadeniz and Thompson (2018), who stated that "teachers often have concerns about technology use, such as how students' paper-and-pencil skills will be affected, how to ensure conceptual understanding, whether to use technology as an exploration tool, or how to design effective lessons that utilize technology appropriately" (p. 2). This foundation of teacher resistance towards using technology would also directly tie into the area of teacher knowledge. Specifically, the concerns about how technology should be used in exploration and lesson design reinforce the importance of developing teacher TPACK. This need was further confirmed by Pittalis (2021), who examined teachers' use of dynamic geometry software. Pittalis found that teachers' perception of how well the tool would fit with their pedagogy and their attitude towards the technology were the factors within the TAM that most affected their intention to use the software (Pittalis, 2021). Once again, the concepts presented directly go towards the teachers' knowledge within the domain of PCK, TPK, and TPACK. Thus, it can be surmised that teacher concerns regarding technology use can be directly linked to teacher TPACK.

Teacher Attitudes in Favor of Adoption and Integration

Despite some teachers' concerns about technology use in the classroom, the overall consensus has been that technology can improve pedagogical practices. Even as far back as 1955, one teacher remarked that calculator use produced enthusiasm in students (Schaughency, 1955). Karedeniz and Thompson (2018) found that "teachers' pedagogical perspectives had a major influence on how they chose to use the technology within their instructional practice, despite any intentions of technology developers" (p. 3). Berlin and White (2012) found that general preservice teachers in mathematics, science, and technology already valued technology integration even before they entered their preservice program. Recent studies have shown an increased perception of the value of technology in mathematics education due to the COVID-19 crisis and the changes that it has caused. For example, Mulenga and Marban (2020) found that digital learning was perceived by mathematics teachers to be a positive response to COVID-19.

Closing Thoughts on Chapter 2

Historically, the use of technology within mathematics instruction has been considered a best practice. The use of technology assets in the classroom is also understood to be an underlying assumption of the current national learning standards in place. How technology is integrated into the classroom can also be effectively evaluated by multiple technology frameworks. These each provide a part of the overall picture of integrating technology successfully in the classroom. Yet, the problem of practice still exists in that technology is not being used to its fullest potential. Furthermore, despite the historical trends and frameworks in place, mathematics teachers do have possible concerns about how technology intersects with the quality of student learning. These concerns are further complicated by negative perceptions that teachers have regarding their own self-efficacy with respect to implementing technology in their instruction. Research further shows that these each of these concerns are partially related to teacher knowledge types and the special knowledge types created by their intersections. Each of these concerns could be an input in the current problem of practice. If teachers lack knowledge or self-efficacy, they cannot be expected to integrate technology in the most effective manner. However, a possible solution does exist in the use of targeted professional development as an intervention. Targeted professional development has the potential to increase self-efficacy in teachers by providing them with the tools and knowledge they need to integrate technology successfully and effectively into their own instruction.

While not present in the current literature it would be fascinating to see how each of the existing technology implementation frameworks intersect with teacher self-efficacy. Specifically, what does technology implementation look like when different and specific self-efficacy levels are known to be present? Also, from this picture what levels of teacher knowledge are then demonstrated once intersections of each framework with self-efficacy are observed?

CHAPTER III PROPOSED SOLUTION

Proposed Solution

Technology has changed the landscape of teaching mathematics. Recent trends from the COVID-19 pandemic have exacerbated the issue. Because of the rapid transitions and paradigm shifts that have taken place, teachers have not received the training they need to use technology in the most effective ways possible during instruction. The ultimate goal of this study was to support mathematics teacher at High School X to more fully leverage technology in the classroom to support student learning. Initial pilot data collected through interviews, observations, and a needs assessment survey showed that this issue is related to a lower level of technology use as reported on the SAMR (Puentedura, 2003), RAT (Hughes et al., 2006), PICRAT (Kimmons et al., 2020), and TIM framework (Kimmons et al., 2020) scales. The needs assessment also revealed a need for improving teacher self-efficacy specific to technology usage. Two professional development (PD) sessions specific to improving teacher TPACK, self-efficacy, and perceptions related to these needs were developed and implemented. The proposed solution was holistically measured through a mixed-methods action research study.

Outline of the Proposed Solution

Mathematics teachers participated in two targeted PD sessions before the beginning of the 2022–2023 school year. Prior to the PD sessions, teachers were administered a pretest survey to establish a baseline score measuring their knowledge and perceptions specific to the problem of practice. Following the PD sessions, a classroom observation was conducted with a sample of nine participating teachers within the first nine-week grading period, using an observation form with components of the TPACK, TIM, and SAMR. Finally, a posttest was administered at the end of the nine-week grading period to all teachers who participated in the PD sessions.

The PD sessions were tailored to the known needs of the teachers in the math department (Avci et al., 2020; Bates & Morgan, 2018; Darling-Hammond et al., 2017; Liao et al., 2017; Lo, 2021). These pedagogical needs were uncovered through my internship classroom observations, an informal pilot needs assessment, and my previous work with teachers throughout the department. The first PD session focused on establishing TPACK about what constitutes higher-level technology use within secondary mathematics instruction. It contained a relatively narrow focus on this issue rather than a broader focus on all of classroom technology. Examples from current department curricula were integrated into the exploration so that teachers could interact actively with their own teaching materials (Liao et al., 2017). Instead of a lecture format, a collaborative inquiry-based approach was used to facilitate a higher level of engagement (Bates & Morgan, 2018). Results of the first session was a collaborative production of ideas about how existing technology and curriculum assets available to teachers within the department could be used at a higher level as defined by the SAMR framework.

The second PD session focused on applying the principles and outputs of the first PD session to the creation and implementation of technology-rich secondary mathematics lessons. To maintain a realistic focus contextualized to the teachers' needs, only technologies available to the department were covered during this session. These technologies included TI-Nspire calculators, iXL, and Nearpod. Descriptions of the current technologies available to teachers were discussed in Chapter 2. Strategies for classroom management during technology-rich lessons were shared, as I identified this need during classroom observations. Once again, a collaborative inquiry-based approach was used (Bates & Morgan, 2018). Collaboration happened within homogeneous groups composed of teachers who teach the same content. Groups were directed to narrow their focus to a lesson that could be observed during the first nine-week grading period, so that the timing of the lessons would coincide with my anticipated observations. The end result of the second session was a collaborative production of a technology-rich lesson that could be implemented in the short-term future. The observation of this lesson was integrated into the measurement of the study.

Justification of Proposed Solution

PD has been shown to be a positive intervention for improving teacher knowledge (Clark-Wilson et al. 2014; Hegedus et al., 2017; Sztajn et al. 2017; Thurm & Barzel, 2020). The seminal work by Loucks-Horsley et al. (2009) established benefits and methods of effective PD specific to the context of mathematics and science education. PD has also been connected to effective teacher technology training. Watson (2006) found that teacher technology training as a form of PD had a long-term positive impact on teachers' self-efficacy. Jiang et al. (2013) studied the impact of PD targeted toward DGS had on teachers' student's achievement. In examining the results of a geometry achievement test, they found that the students of teachers with extensive PD related to the use of DGS significantly outperformed other students whose teachers did not receive the PD intervention. However, Thurm and Barzel (2020) noted, "little is known about the efficacy of professional development programs for teaching mathematics with technology" (p. 1411). Nevertheless, Thurm and Barzel acknowledged that technology PD for mathematics teachers increased their degree of positive technology-related beliefs and their frequency of technology use. Bowman et al. (2020) also concluded that PD was the most effective means of enhancing technology-related skills in teachers. One can thus conclude that the use of targeted PD to address the problem of technology usage within mathematics education has been suggested as a possible valid and viable solution.

The PD sessions were also a valid solution because they were contextualized to the needs of the current context. The contextualization of PD to the target audience's needs and context has been established as crucial by multiple researchers (Avci et al., 2020; Bates & Morgan, 2018; Darling-Hammond et al., 2017; Liao et al., 2017; Lo, 2021). As noted above, I identified these needs through my internship, classroom observations, an informal needs assessment, and my previous work with teachers throughout the department. The PD sessions were also justifiable as a solution because they heavily relied upon collaborative active learning through inquiry-based learning (Avci et al., 2019; Bates & Morgan, 2018; Liao et al., 2017).

The amount of PD sessions planned was also appropriate. Practical local constraints prevented me from executing a sustained ongoing PD. Many authors (Avci et al., 2020; Bates & Morgan, 2018; Darling-Hammond et al., 2017; Lo, 2021; Loucks-Horsley et al., 2009) have highlighted the benefits of a PD initiative that is sustained in duration. Long-term PD often enhances ongoing feedback, continuous improvement (Bates & Morgan, 2018), and sustainability (Liao et al., 2017). However, the participants' context must also be taken into consideration. Contextualizing PD to the specific teachers and school where it will be delivered is a primary concern among teachers (Liao et al., 2017). This contextualization includes tailoring not only the content of the PD sessions but their format as well. As discussed in chapter 1, no sustained PD initiatives have continued successfully beyond one or two sessions at High School X in recent years. Lydon and King (2009) found a lack of teacher interest in long term PD situations to be a contributing factor to teachers responding better to shorter PD sessions. Thus, if the context of the teachers was to be honored, the format of the PD sessions had to be limited to at most two sessions. Once again, practical local constraints prevented me from implementing a more long-term PD initiative. Moreover, PD sessions at High School X have rarely occurred during the school year, except for some teacher training immediately before school or on special days when students are not present. Therefore, to offer PD in the manner that is most convenient for teachers, a pair of PD sessions at the beginning of the year seemed preferable. Besides, sustained duration is not a prerequisite for success. Lydon and King (2009) showed that short-duration PD focused on practicality and interactivity could also have a positive long-term impact on teachers. Thus, the plan for the PD sessions was justifiable in terms of both content and format.

Study Context and Participants

The study was conducted within the mathematics department at High School X. The participants were the teachers within the department. Approximately 20 teachers were involved in the pretest and posttest and in the PD sessions. As of the 2021-2022 school year, roughly one-third of the teachers in this department had less than five years of teaching experience. One-third had between five and ten years of teaching experience. The final third of teachers had between ten and thirty-three years of teaching experience. 80% of the department were women and 20% men. 80% of the department were also White. It is noteworthy that the breakdown of teacher demographics in the mathematics department did not align with the student demographics of High School X. Due to the nature of the study and context, participation was voluntary. A sample of nine participants was observed during instruction. I selected these participants in two ways. I first included a supplementary question in the pretest that asked each participant if they were willing to be observed. Once the pretests are collected, I divided the participants into a low, middle, and high group based on their total score. I then chose three participants from each group to observe.

The Proposed Research Paradigm

I conducted this mixed-methods action research study to understand the impact targeted PD can have on effective secondary mathematics instruction with technology. A mixed-methods approach was vital. Quantitative data allowed me to observe and measure what participants knew about effective technology use in mathematics instruction and how they perceived the level of technology they integrate and their self-efficacy with respect to technology integration. Qualitative observations enabled me to determine how the teachers function in practice with respect to demonstrations of knowledge and level of technology use. Mixing the methods allowed the research to correlate and corroborate both sets of results. For example, did the teachers' self-reported assessment of their knowledge and practices align with what the observations revealed?

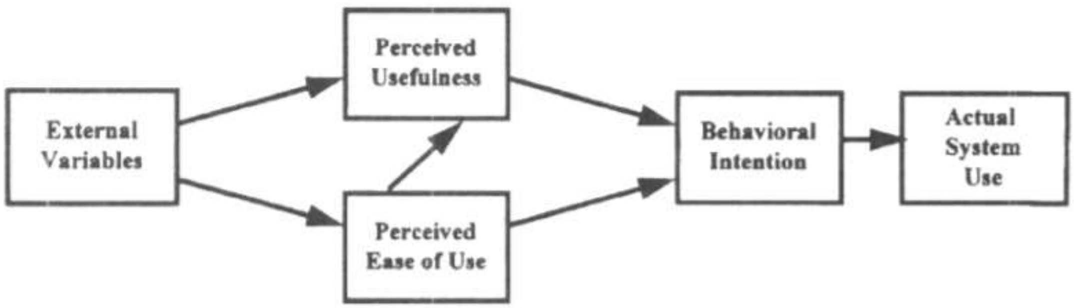
In support of this design, a concurrent mixed-methods action research approach was used. Ivankova (2015) defined the purpose of a concurrent mixed methods study as "to compare or merge quantitative and qualitative results to produce well-validated conclusions" (p. 129). The reasons for this mixed-methods approach included both complementarity and triangulation (Ivankova, 2015; Plano Clark & Ivankova, 2016). Complementarity permitted reaching a more complete conclusion; triangulation, or comparison of the qualitative and quantitative results, making it possible to observe convergences in the data (Plano Clark & Ivankova, 2016). In this way, I was able to obtain conclusions that were more meaningful and complete about the impact that technology rich PD sessions can have on teacher TPACK and how effectively they integrate technology in secondary mathematics instruction. (Ivankova, 2015).

The Modified Technology Acceptance Model

The seminal work by Davis (1985) established a model for understanding how technology is accepted and then used. The original model proposed that certain variables immediately impact the end user's perception of how easily the technology can be used and how useful the technology could be. The perception of ease of use was also noted as influencing the perception of usefulness. These two perceptions then became inputs that determined the end user's behavioral intention to use the technology. Finally, this behavioral intention became the input that determined the output of actual use. Figure 5 shows the original model.

Figure 5

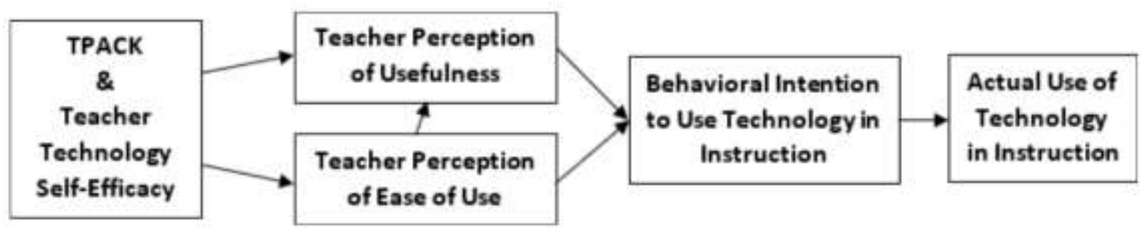
Original Technology Acceptance Model.



This model can be modified to assist the understanding of mathematics teachers' technology use. Joo et al. (2018) also used the TAM to directly tie self-efficacy and TPACK with classroom technology use. The initial inputs to this model are TPACK and teacher self-efficacy with specific respect to technology use within the context of mathematics instruction. In the initial stage, the perception of self-efficacy is generalized to overall self-efficacy with respect to technology. The use of self-efficacy as a direct influencer of behavior is supported by the seminal work of Bandura (1977). This stage is not specific to the individual technology asset being used. Essentially, the inputs to the model are summarized as a) what teachers know about teaching their specific content with technology and b) how they perceive their ability to teach their specific content with technology as a whole (Joo et al., 2018). Teachers' knowledge of technology and their self-perception of their overall ability using technology immediately determine how they perceive a specific technology asset as its ease of use and usefulness in the context of mathematics instruction. Once again, based on the original model, how easily teachers perceive using a technology asset will determine their perception of how useful this technology will be in the course of instruction. Thus, the perception of usefulness has dual inputs. These two perceptions directly impact and inform teachers' behavioral intention to use a specific technology asset in instruction. This intention then impacts their actual final use of technology in this context. Figure 6 provides the resulting modified model.

Figure 6

Modified Technology Acceptance Model



The logic of this model provides several implications that inform possible ways to impact the desired result of using technology competently in instruction. If teachers have little knowledge of how to effectively use technology for instruction in their content area, then their perceptions, intention, and behavior will be compromised. The same is true regarding self-efficacy. If teachers perceive themselves as unable to effectively use technology for instruction, then their perception of its usefulness, their intention, and their ultimate behavior will be compromised. If teachers have a foundation of TPACK and self-efficacy but do not find a specific technology asset to be useful or easy to use, then a disconnect between knowledge, self-efficacy, and behavior will exist. From this adapted model, it was hypothesized that improving the quality of TPACK, self-efficacy with respect to technology, and perceptions of individual technologies would have a positive impact on the desired behavior of effectively using technology within mathematics instruction.

Technology Integration and Use Frameworks

Having defined the plausible inputs related to the ultimately desired behavior, I established a framework as to how effective technology usage can be evaluated within the mathematics classroom. In chapter 2, I discussed Technological Pedagogical Content Knowledge (TPACK; Kohler & Mishra, 2009), Substitution, Augmentation, Modification, Replacement (SAMR; Puentedura, 2003), Replacement, Amplification, Transformation (RAT; Hughes et al., 2006), the Technology Integration Matrix (TIM; Harnes et al., 2016), and Passive, Interactive, Creative, Replacement, Amplification, Transformation (PICRAT; Kimmons et al., 2020). Each framework seems to contain a piece of the big picture of how technology is integrated in the classroom.

TPACK (Kohler & Mishra, 2009) contains a robust view of teacher knowledge, as both an input that contributes to success and a measurable aspect that can be demonstrated. These characteristics are evidenced in the myriad of studies that have observed and measured TPACK. However, with regard to effective technology integration, TPACK is not an end in itself. It measures what teachers know about teaching and facilitating knowledge creation while using specific technology assets within the context of a specific content domain (Kohler & Mishra, 2009). This framework does not fully measure or examine the quality with which technology is used within instruction. Another shortfall of this framework is that it is highly teacher-centered.

Other frameworks such as PICRAT (Kimmons et al., 2020) and TIM (Harnes et al., 2016) have introduced a primary focus on the student-centered nature of technology usage.

PICRAT (Kimmons et al., 2020) classifies student technology use as either passive, interactive, or creative. Creative, transformative use by students is the apex of success in this framework. The TIM (Harnes et al., 2016) contains multiple examples of a student-centered focus. The "levels of technology integration" scale (entry, adoption, adaptation, infusion, and transformation) includes verbiage that focuses on student choice and actions (Harnes et al., 2016). Additionally, the defining "characteristics" ranked using this scale include a focus on students' active role in leading learning and collaborating (Harnes et al., 2016). If we focus on student-centered actions and use, then how can we not also focus on student-centered knowledge?

If a student-centered approach is valued, there must also be an equivalent focus on the demonstration of student knowledge with respect to technology and its subdomains. Granted, a student's demonstration of knowledge about how to teach is not necessarily relevant to this context. However, the knowledge domains of TK, CK, and TCK are highly relevant. These can be separated from their teacher knowledge counterparts by distinguishing them as Student Technology Knowledge (STK), Student Content Knowledge (SCK), and Student Technological Content Knowledge (STCK). Successful technology use requires students to possess and demonstrate knowledge about technology, content, and how to use technology effectively within the context of a particular area.

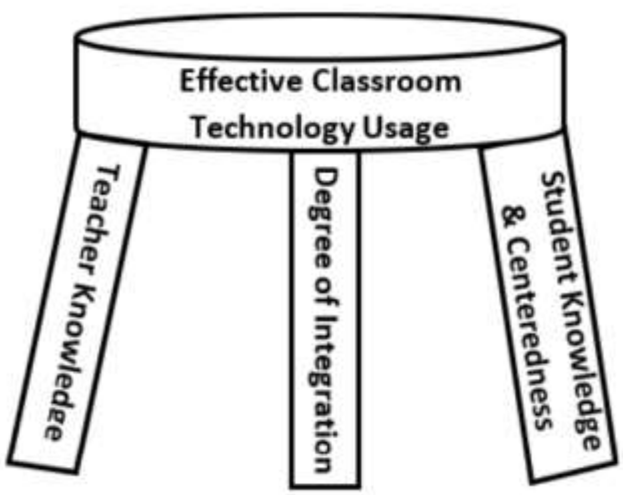
However, although knowledge itself is vital, the execution of knowledge is equally important. TPACK fails to address this factor fully. SAMR (Puentedura, 2003), RAT (Hughes et al., 2006), TIM (Harnes et al., 2016), and PICRAT (Kimmons et al., 2020) each provide approaches to considering the degree of effectiveness and quality of use. As previously discussed, TIM is unique in that it focuses on five types of learning and measures each one in isolation from each other. PICRAT is highly similar to RAT in that Kimmons et al. (2020) modified RAT to include a second dimension of student-centeredness. RAT and SAMR also have similarities in their approach to measuring the overall level of technology use. However, although the initial and final levels of RAT and SAMR are essentially the same, there is a noticeable difference in the middle classification. RAT jumps from a middle level of technology use that produces no fundamental change up to the highest level possible of transformation, whereas SAMR includes a lower-middle level of augmentation in which technology does add some functional improvement. Comparing the two on the criterion of the level of change that the technology introduces, it would seem that the second level of RAT would best align with a combination of the lowest two levels of SAMR. Because of its more nuanced distinctions between the types of improvements, efficiency, and effectiveness brought about by technology, SAMR is the more logical choice for evaluating technology usage within classroom learning.

Once again, however, SAMR is not complete in its coverage. It fails to take into consideration the need for demonstration of knowledge. If the goal is to examine evidence of knowledge types that are known to be contributing factors, then the implementation of technology alone is not enough. Students can potentially demonstrate the learned processes involved with implementation without demonstrating strong knowledge types. If the goal is to maintain an appropriate student-centered focus, then neither SAMR nor TPACK is sufficient apart from each other.

How can the valued demonstrations of teacher knowledge types, student knowledge types, and levels of technology use be holistically viewed in a single snapshot? To keep a holistic view, I used a combination of the SAMR, TPACK, and TIM frameworks to define the desired knowledge and level of technology integration. This relationship between technology use, teacher knowledge, and student knowledge and centeredness can be conceptualized with a diagram of a stool (Figure 7). Without each of the three legs of teacher knowledge (measured by TPACK and its subdomains in this study), student knowledge and centeredness (aligned with a five-level system like TIM), and degree of technology integration (measured through SAMR in this study), then the stool will not be stable. If one leg is substantially lower or higher than another, then a lack of balance will be present, leading to the compromise of the instructional process. This is not to say that instruction cannot take place. Rather the optimal effectiveness is compromised. Combining these aspects from these three existing frameworks helped to maintain a holistic student-centered, knowledge-based focus on effective classroom technology usage, and it was used as the primary lens through which the qualitative observations were conducted.

Figure 7

Diagram of the Combined Frameworks.



Data Collection Methods

Restatement of Research Questions

In Chapter 1, I established the following research questions for this study:

1. What impact, if any, do focused technology-rich PD sessions have on improving mathematics teachers' self-perceptions of their TPACK, technology integration, and self-efficacy with respect to technology?
2. After attending focused technology-rich PD sessions, what evidence of TPACK and level of technology integration is observed during a technology-rich lesson?
3. After attending focused technology-rich PD sessions, how do the self-perceptions of teachers compare to what is observed during a technology-rich lesson?

These three questions were addressed by two strands of data in this mixed-methods action research study. The first research question was directly measured by the pretest/posttest survey (Appendix B) that were conducted. The second research question was directly measured by the classroom instruction observation form (Appendix C). The third research question was measured by mixing the results of the pretest/posttest survey and classroom instruction observation form. Each of these metrics also aligned with the legs of the combined framework previously illustrated in Figure 7. The first research question addressed the legs of teacher knowledge and degree of integration. The second and third research questions addressed all three legs. These legs and research questions were also aligned with both PD sessions. Equal coverage of each research question was present in both PD sessions. Table 1 below shows a crosswalk of the research questions, framework legs, and instruments.

Table 1

Crosswalk of Research Questions, Legs of Combined Framework and Instrument

	Leg of Combined Framework	Instrument
Research Question 1	Teacher Knowledge & Level of Technology Integration	Pretest/Posttest Survey
Research Question 2	Teacher Knowledge, Level of Technology Integration, & Student Centeredness and Knowledge	Classroom Observation Form
Research Question 3	Teacher Knowledge, Level of Technology Integration, & Student Centeredness and Knowledge	Pretest/Posttest Survey & Classroom Observation Form

Data Collection for Research Question 1

The effectiveness of the targeted professional development sessions was measured through a quantitative pretest and posttest survey along with qualitative observations. I developed a pretest/posttest survey by examining existing metrics used in 15 separate studies (Akyuz, 2018; Alrwaished et al., 2020; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Kaya & Dag, 2013; Koh & Chai, 2014; Lee & Tsai, 2010; Meriç, 2014; Niederhauser & Perkmen, 2008; Saltan & Arslan, 2017; Schmidt et al., 2009; Semiz & Ince, 2012; Young et al., 2013; Zhan et al., 2013). These metrics focused on the areas of TPACK, the level of technology use, and self-efficacy. The pretest/posttest survey (Appendix B) contained 40 questions, each of which were answered on a 5-point Likert scale. These 40 questions can be divided into six categories: TK (questions 1 to 7), TCK (questions 8 to 15), TPK (questions 16 to 21), TPACK (questions 22 to 32), level of technology use (questions 33 and 34), and self-efficacy (questions 35 to 40). While TPACK is the knowledge domain that is aligned with the research questions, measuring TPACK is not complete without also measuring the subdomains of TK, TCK, and TPK that contribute to TPACK. The pretest and posttest survey were administered to all teachers who participated in the professional development sessions. To measure more completely, I gave the pretest before any PD session was implemented. Participants then took the posttest survey twice. I first administered the posttest survey immediately after the last PD session. This allowed me to measure immediate changes in self-perception. I administered the posttest a second time at the end of the first grading period after all nine observations were completed. This allowed me to measure the longer-term impacts of the PD on the reported categories.

Data Collection for Research Question 2

A classroom instruction observation form (Appendix C) was also designed, based on the components of the TIM, SAMR, and TPACK frameworks. It is important to note that this form served as the primary artifact of this Record of Study. Using this form, I examined evidence of teacher knowledge, student knowledge and centeredness, and the level of technology implementation. These sections of the observation form corresponded to the primary aspects of the TIM, SAMR, and TPACK frameworks. The sections also aligned with the modified TAM previously proposed. As was previously discussed, a sample of nine participants were observed during instruction. The final question of the pretest survey asked teachers if they were willing to be observed during the instruction of a technology-rich lesson. To maximize the variability of my observations, I used two factors in selecting the nine participants from among those who indicated on the pretest survey that they were willing to be observed. I first considered selecting teachers to observe based on their initial total score. This factor allowed me to select teachers who varied in initial self-perception. I also considered selecting teachers to observe based on the amount of change in their scores from the pretest survey to the first posttest survey.

Justification of the Use of Instruments in This Context

The use of a pretest and posttest is highly supported by current research (Akyuz, 2018; Alrwaished et al., 2020; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Kaya & Dag, 2013; Koh & Chai, 2014; Lee & Tsai, 2010; Meriç, 2014; Niederhauser & Perkmen, 2008; Saltan & Arslan, 2017; Schmidt et al., 2009; Semiz & Ince, 2012; Young et al., 2013; Zhan et al., 2013). Studies that did not employ a modified measuring tool were not used as sources for metric development; rather, my development work relied only on these 15 studies that presented and applied a unique assessment metric. Each question used to assist teachers was compiled into a master list, and I then categorized the questions according to their alignment with TK, TCK, TPK, TPACK, level of technology use, or self-efficacy specific to technology usage. After that, I grouped the questions within each category and distilled their content into a set of 40 questions that would provide coverage across the topics. The studies from which the questions were taken measured teacher knowledge in similar situations. One should note that one of the authors of the TPACK assessment tool introduced by Schmidt et al. (2009), which was modified by subsequent researchers, was also an original author of the seminal work on TPACK. Thus, the metrics used for evaluating TPACK and its subdomains were closely aligned with those proposed by the original authors who proposed TPACK.

The classroom observation form provided a detailed view of a teacher's capacities regarding effective technology usage in the classroom. I created the observation form by looking at the core aspects within the SAMR, TIM, and TPACK theoretical frameworks for knowledge and technology integration. I then sectioned off areas to accommodate targeted observation evidence of each core aspect. This qualitative observation permitted me as the researcher to record specific evidence of whether the teacher was using the technology in ways consistent with his or her indications of knowledge and self-efficacy. This observation form allowed me to record targeted evidence of TPACK, student knowledge, SAMR levels, and student-centeredness. Each area of observation was directly tied to my research questions.

The selection of teachers for the observations was also justifiable. Only willing teachers were selected. If a teacher was not willing, then the unwillingness and uncomfortableness of the participant could have confounded the quality of the observation data. As was previously stated, I selected teachers using two factors. These two factors were their initial total score on the pretest survey and the change in score between the pretest survey and the first posttest survey. This ensured that a fair representation of teachers was used for the observations and mixed methods analysis. This type of blocking allowed perceived ability, knowledge, and change in score to be removed as a variable confounding the impact of the targeted PD sessions on the desired result.

Data Analysis Strategy

Analysis Strategy for Research Question 1

The pretest and posttest surveys were analyzed using descriptive statistics and a matched-pair hypothesis *t*-test (Urdan, 2017). Descriptive statistics measured attributes of central tendency (mean, median, and mode) and variability (standard deviation, range, and interquartile range) (Urdan, 2017). I assessed the reliability of each of the subscales. After ensuring acceptable reliability ($\alpha > .70$), mean scores for each subscale were calculated. These mean scores were used in the matched pair t-tests. The use of the matched-pair hypothesis *t*-test determined whether the differences in average scores on the sections of the pretest and posttest was statistically significant. I performed this test twice. I first analyzed the differences in section scores between the pretest survey and a posttest survey given immediately after the PD session. I analyzed the differences in section scores between the pretest survey and the posttest survey given at the end of the first grading period. From this I was able to compare the immediate and longer-term impact of the PD sessions on each pretest and posttest survey category.

Analysis Strategy for Research Question 2

The observation forms were analyzed qualitatively (Borgstede & Scholz, 2021; Johnson & Christensen, 2020), using the steps and processes proposed by Creswell and Creswell (2017) and Bhattacharya (2017). The observation forms were first organized separately and prepared for analysis. Codes (Bhattacharya, 2017) were used relevant to the study context. These codes were common phrases and ideas that stand out (Miles et al., 2020) or align with the primary aspects of TPACK, self-efficacy, technology effectiveness, and technology perceptions. Common themes that emerged within these codes were identified and described. A level of technology use based on the SAMR model was assigned to each lesson. It is understood that multiple examples of technology use would likely have been present in the observed lesson due to the nature of mathematics teaching today. Thus, while I recorded all evidence of technology integration, the recorded SAMR level for the lesson was based on the highest level demonstrated in the lesson.

Analysis Strategy for Research Question 3

Data from the qualitative and quantitative strands was first analyzed separately. Initial qualitative and quantitative conclusions were reached. Quantitative conclusions focused on the distribution of scores on sections of the pretest and a comparison between the differences of scores. Qualitative conclusions focused on describing the types of knowledge demonstrated and the level of technology integrated as measured by SAMR. Once the individual strand analyses were completed, mixing of the results occurred. A joint analysis was conducted. I prepared a comparative description of my comments on the observation of a teacher's instruction and the teacher's perception as expressed by their self-evaluation in the second posttest. This was completed for each aspect in which there was overlap between the observation and posttest. These categories included level of technology use as measured by SAMR and each type of teacher knowledge that comprises TPACK. Since SAMR is a scaled measurement, I compared the highest level of technology usage observed during the lesson to the scores recorded in each section of the second posttest. This also allowed me to compare observed SAMR level to both knowledge and self-efficacy. I also compared the levels of knowledge types recorded in the posttest to what was observed during the lesson. Comparing the qualitative observations of teachers during instruction to their quantitative self-reported answers also allowed me to issue a comparative statement that addressed the perceived difference in pretest and second posttest survey scores. Finally, the significance of these comparisons was examined, and an overall qualitative comparison was made with the goal of arriving at a meta-inference (Ivankova, 2014) about whether the PD sessions led to an increase in the effectiveness of technology use as demonstrated by increases in teacher knowledge, perception, self-efficacy, and practice.

Timeline

The pretest was administered in early August 2022. Immediately following the pretest, the PD sessions were offered. Over the course of the next nine weeks, as the school year began, nine teachers were observed during a technology-rich lesson of their choice. At the end of the nine-week period, a posttest was administered to all participants.

Reliability and Validity

The voluntary participation nature of the study could have affected the reliability of the results, but this feature was unavoidable as participants could not be compelled to participate. Also, the self-reported nature of the pretest and posttest presented a limitation, since individuals' perceptions about themselves could have differed from what an objective observer may determine. However, the use of the qualitative observation form allowed for comparison in conjunction with the self-reported assessment.

The qualitative aspect of the study had validity because the story of the individual participant was honored. All participants had the opportunity to provide a demonstration of their technology usage. This demonstration provided teachers an opportunity to give a type of definition of how they viewed the level of technology use, self-efficacy, and knowledge that they had reported. Again, the use of the observation form allowed me to put these data into perspective through a comparison with what I saw the teachers doing.

The mixed-methods design used in this study also had content validity. Ivankova (2014) established that for content validity to be present, the instrument must measure the phenomenon in a way that takes into consideration all the aspects of a situation. This was true for the present study design. The underlying framework of this study was founded upon the modified TAM, SAMR, TIM, and TPACK frameworks. The proposed combination of measurement tools fully encapsulated the components of the framework. It also established reliability because it effectively and accurately measured these aspects (Ivankova, 2014).

Closing Thoughts on Chapter 3

Through this study I hoped to use a unique holistic approach to examine technology use by secondary mathematics teachers. The problem of assessing the effectiveness of technology use within mathematics instruction is so complex that I had to examine it using several established frameworks. This need was evidenced by my discussion of the limitations of existing models. I used these frameworks to examine the inputs of teacher knowledge, self-efficacy, and perceptions and how they are influenced by targeted PD. Data was collected by both qualitative and quantitative methods and was analyzed through quantitative, qualitative, and mixed methods.

CHAPTER IV: ANALYSIS AND RESULTS/FINDINGS

Introduction to the Analysis

The purpose of this study was to examine the potential impact of providing targeted PD on the effectiveness of classroom technology use by teachers as measured by TPACK, SAMR, and self-efficacy. Prior to this study, internship fieldwork provided insight into the needs of secondary mathematics teachers at High School X, specific to the use of technology within the classroom. Two targeted PD sessions were designed and implemented during the pre-school-year training time allotted by the district. The content of the PD sessions was planned based on my internship classroom observations, interviews with teachers, and pilot data survey (see Chapter 3 for more detail). Prior to attending the first session, all participants completed a digitally administered pretest survey. Immediately following the second session, all participants completed the first posttest survey. Over the subsequent nine weeks, I conducted nine observations of classroom instruction delivered by participants who volunteered to be observed during the implementation of a technology-rich lesson of their choice. This time period coincided with the first grading period of the school year. Qualitative data were collected using the observation form presented in Appendix C. At the end of this nine-week period, a second posttest was digitally administered to all participants. I analyzed the quantitative data obtained from the pretests and posttests using descriptive statistics and a matched-pairs *t*-test. The qualitative data were analyzed by coding the data for themes related to the components of the compiled theoretical framework discussed previously in chapter 2. Finally, I merged the quantitative and qualitative data to provide a mixed-methods examination of the use of targeted PD to increase the effectiveness of technology use in classroom instruction by secondary mathematics teachers.

Research Question 1

Presentation of Data

Overview of Pretest and Posttests

The first research question was as follows: What impact, if any, do focused technology-rich PD sessions have on improving mathematics teachers' self-perceptions of their TPACK, technology integration, and self-efficacy with respect to technology? This question was measured by the pretest and two posttests. The pretest was given before the first PD session. The first posttest was given immediately after the second PD session. The second posttest was given at the end of the first nine-week grading period. Within the pretest and posttests, there were six distinct categories. Although each question was measured on the same 7-point Likert scale, the categories themselves contained different numbers of questions, with the result that point totals for different categories are not directly comparable. The raw results are presented below in Table 2. This table summarizes the descriptive statistics of each subscore category. To accurately compare the subscore categories, I analyzed the percentages of change between the pretest and posttests using descriptive statistics. These percentages of change are summarized in Table 3.

Table 2

Descriptive Statistics for Subscore Category Scores

Category	Test	Mean	SD	Range	IQR	Median	Min	Max
TK	Pretest	39.70	5.15	19	6.75	39	29	48
	Postest1	42.95	4.61	14	7.5	44.5	35	49
	Postest2	41.20	7.88	32	9.75	43.5	16	48
TCK	Pretest	43.45	5.99	24	7.5	44	30	54
	Postest1	48.60	5.66	18	10.75	50.5	38	56
	Postest2	46.75	9.34	40	6.25	48	16	56
TPK	Pretest	32.60	4.98	18	7	34	22	40
	Postest1	35.40	4.92	13	9.75	35.5	29	42
	Postest2	36.00	6.97	30	4.75	36	12	42
TPACK	Pretest	56.10	10.38	36	17	58	35	71
	Postest1	64.70	9.32	30	17.25	67	47	77
	Postest2	64.20	12.68	55	12.25	67	22	77
SAMR	Pretest	8.80	2.33	9	2.75	9	3	12
	Postest1	9.75	2.61	8	4.75	10	6	14
	Postest2	10.25	2.67	10	3	10	4	14
SE	Pretest	32.20	5.42	16	9.5	34.5	23	39
	Postest1	35.45	5.48	15	11.75	35.5	27	42
	Postest2	35.00	7.34	30	8	36	12	42

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology

Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

Table 3 *Descriptive Statistics for the Percentage Change in Subscore Totals Between the Pretest, Posttest 1, and Posttest 2*

	Test	Mean	SD	Range	IQR	Median	Min	Max
TK	Pretest vs. Posttest 1	8.91%	10.01%	33.02%	17.57%	6.43%	-8.70%	24.32%
	Pretest vs. Posttest 2	4.96%	19.59%	88.29%	21.72%	9.95%	-66.67%	21.62%
TCK	Pretest vs. Posttest 1	12.78%	12.19%	50.92%	13.70%	12.00%	-4.26%	46.67%
	Pretest vs. Posttest 2	8.96%	23.43%	115.22%	16.17%	13.53%	-65.22%	50.00%
TPK	Pretest vs. Posttest 1	9.52%	12.70%	46.75%	12.80%	6.62%	-8.82%	37.93%
	Pretest vs. Posttest 2	11.60%	23.69%	120.78%	22.89%	9.56%	-57.14%	63.64%
TPACK	Pretest vs. Posttest 1	17.00%	14.30%	55.35%	20.04%	15.94%	-6.78%	48.57%
	Pretest vs. Posttest 2	17.21%	29.07%	129.68%	31.25%	15.09%	-56.00%	73.68%
SAMR	Pretest vs. Posttest 1	17.23%	42.44%	200.00%	25.00%	17.42%	-33.33%	166.67%
	Pretest vs. Posttest 2	21.53%	32.93%	150.00%	47.50%	16.25%	-50.00%	100.00%
SE	Pretest vs. Posttest 1	10.87%	10.49%	37.50%	17.22%	8.22%	-9.38%	28.13%
	Pretest vs. Posttest 2	10.04%	24.18%	107.14%	30.47%	7.69%	-57.14%	50.00%

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

Reliability

To determine the reliability of the scores of six subscore sections of the quantitative data collection instrument, I first conducted a reliability test and calculated Cronbach's alpha for each of the six sections. This test was conducted using SPSS. Prior to the test, a level of 0.7 was set as the minimum desired level of reliability (Urdan, 2017). In each case, the test reported Cronbach's alpha to be higher than 0.90. Thus, reliability was confirmed for all portions of the quantitative data collection instrument. Table 4 presents the levels of reliability for each subscore.

Table 4

Reliability of Subscore Sections

Subscore Category	Reliability
TK	0.94
TCK	0.97
TPK	0.99
TPACK	0.98
SAMR	0.97
SE	0.98

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

First Posttest Data

The overall comparison of the results of the pretest and first posttest turned out as expected. Since this posttest was given immediately after the last PD session, it was assumed that each of the section subscores would increase. When a preliminary matched-pairs *t*-test was executed for each of the subscores, a statistically significant increase was found for all of them. Thus, the initial data indicate that the immediate desired result was achieved.

The average changes in the various sections were quite close to each other, ranging from a 9% increase to a 17% increase. The lowest percentage increase on average was found in the TK section. This is understandable as the overall content of the professional development session did not focus exclusively on TK as a primary consideration. Rather, the focus of TK was integrated into each of the additional technology knowledge areas. Interestingly, the TPACK and SAMR categories had nearly equal average changes of about 17%.

Yet there was also significant variability in the results. The SAMR results demonstrated the greatest volatility of any of the subsections. This category tied for the highest average percentage increase reported by participants, but the range of individual results was very high, at 200% (from a decrease of 33% to an increase of 167%) when compared to the other subscript or categories. No other subsection had such large volatility. Also, 25% of participants showed either no increase or a decrease in their score, yet the upper 25% of participants showed an increase of greater than 25%, with the remaining half showing a score change ranging between 0% and 25%. These data were also highly skewed in their distribution; the skewness was affected by the definite presence of outliers.

The results of the SAMR section are interesting given the prevalence of this subscore content in both PD sessions. This aspect was presented in the first session and was then reinforced at the beginning of the second session. This section of knowledge was also highly integrated into the lesson design process presented in the second session.

TCK and TPACK had comparable maximum increases in their subscores. Overall, the increases and decreases of each of these two sections were very similar. Both contained very similar ranges, minima, and maxima. TPK showed slightly less improvement of knowledge than these two categories. This is interesting given that TCK and TPK combine to make up TPACK.

Of particular interest was the smaller change in the self-efficacy subscore category, relative to what was expected. I presumed according to the original conceptual framework model modified after Davis (1985) that self-efficacy would be directly influenced by the input of knowledge and would itself then also serve as an input increasing effectiveness in technology implementation. At most, there was a 28% increase in the self-efficacy score, with an average score increase of 11%. However, the range and standard deviation were much smaller. Thus, less variability is indicated. This indicates that the self-efficacy levels reported by participants was similar and less variable. More than 75% of participants showed some increase in their score in this subsection. Thus, while not as strong as the other increases, the improvement was solid and positive.

Pretest versus Posttest1 Results

For each *t*-test, a significance level of 0.05 was assumed. SPSS (version 28, IBM) was used to conduct the statistical significance tests, and a secondary method using the TI-Nspire software verified the test results. Table 5 below shows the results. Based on the chosen level of significance, each test but one showed a statistically significant increase in self-reported scores by participants after attending technology-rich PD sessions. The lone category that did not show a statistically significant increase was the category of self-efficacy. Descriptively, the categories also showed change. As Table 2 demonstrates, the average change for each category was between approximately 9% and 22%. The data calculations also indicated that at least 75% of participants demonstrated a score improvement in each category on posttest 1. Thus, the immediate impact of technology-rich PD sessions was an increase in reported knowledge, technology use, and self-efficacy.

Table 5

Pretest Versus Posttest 1: Significance Test Results

	Mean Difference of Posttest 1 and Pretest (SD)	t (df)	*p*
TK	3.25 (3.77)	3.85 (19)	0.001
TCK	5.15 (4.40)	5.23 (19)	0.001
TPK	2.80 (3.55)	3.53 (19)	0.002
TPACK	8.60 (6.06)	6.36 (19)	0.001
SAMR	0.95 (2.16)	1.96 (19)	0.064
SE	3.25 (3.04)	4.78 (19)	0.001

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

Second Posttest Data

The second posttest produced results somewhat similar to the first posttest. Overall, each subscore section showed an increase in average score when compared to the pretest. However, with the exception of the SAMR subscore, variability also increased significantly for the various subscores, as indicated by the standard deviations, ranges, and interquartile ranges. Notably, although the variability of the SAMR subscore decreased, this subscore still demonstrated the greatest variability. The range decreased from 200% to 150% and the standard deviation from 42% to 33%. SAMR also showed the greatest increase in the amount of change, at approximately 22%.

The subscore sections of TK and TCK did increase from the pretest to posttest 2. However, the percentage of change decreased from posttest 1 to posttest 2. Thus, it is not clear whether change was sustained or maintained during the nine-week period between posttest administrations. Each of the other sections showed an average change on posttest 2 that was approximately equal to or greater than that on posttest 1. From a descriptive standpoint, it seems that the change indicated by posttest 1 was sustained by the time of posttest 2 in the categories of TPK, TPACK, SAMR, and self-efficacy.

Computing the quartiles of the data showed that the majority of participants demonstrated change on the second posttest in all subscore categories except TK. The medians showed that more than 50% of the participants showed change in every category. The maxima for the various categories showed that, with the exception of TK, the highest increase was at least 50%. The highest increase reported in any subsection was a 100% increase in the SAMR category. A five-number summary for each percentage increase calculation is presented below in Table 6.

Table 6

5 Number Summary for the Percentage Change in Subscore Totals Between the Pretest, Posttest 1, and Posttest 2

Category	Test	Min	Q1	Median	Q3	Max
TK	Pretest vs. Posttest 1	-8.70%	0.52%	6.43%	18.10%	24.32%
	Pretest vs. Posttest 2	-66.67%	-4.29%	9.95%	17.44%	21.62%
TCK	Pretest vs. Posttest 1	-4.26%	3.89%	12.00%	17.59%	46.67%
	Pretest vs. Posttest 2	-65.22%	2.67%	13.53%	18.84%	50.00%
TPK	Pretest vs. Posttest 1	-8.82%	2.59%	6.62%	15.38%	37.93%
	Pretest vs. Posttest 2	-57.14%	1.25%	9.56%	24.14%	63.64%
TPACK	Pretest vs. Posttest 1	-6.78%	7.30%	15.94%	27.34%	48.57%
	Pretest vs. Posttest 2	-56.00%	1.06%	15.09%	32.30%	73.68%
SAMR	Pretest vs. Posttest 1	-33.33%	0.00%	17.42%	25.00%	166.67%
	Pretest vs. Posttest 2	-50.00%	0.00%	16.25%	47.5%	100.00%
SE	Pretest vs. Posttest 1	-9.38%	2.87%	8.22%	20.09%	28.13%
	Pretest vs. Posttest 2	-57.14%	0.00%	7.69%	30.47%	50.00%

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

TPACK emerged as the second-highest area of change on the second posttest. This finding is significant for the context of the present study as TPACK represented a substantial portion of the theoretical framework that underpinned the study. On average, the scores increased by 17%, representing strong continuation of change relative to that prior to posttest 1. More than 75% of participants showed change in this category, with a maximum reported change of approximately 74%.

Self-efficacy also remained consistent between the two posttests. The two averages were within 0.8% of each other. The variability of change in this category was also smaller than in other categories. The largest increase in participant score was 50%. Given the median of 7.69%, we can deduce that half of participants had score increases between 8% and 50% in self-reported self-efficacy with respect to technology use.

The descriptive results were positive with respect to the established components of the theoretical framework. The three primary components of the theoretical framework were SAMR level, self-efficacy, and knowledge as defined by TPACK. The subcomponents of TPACK did not show equal success as compared each other and the category of TPACK. However, TPACK as a whole showed the second-highest increase overall. SAMR level showed the highest increase. Self-efficacy did not exhibit as great an increase, but the improvement was consistent. Therefore, the results of posttest 2 were generally positive in the context of the theoretical framework.

Pretest versus Posttest 2 Results

Whereas the comparison between the pretest and posttest 1 showed a statistically significant increase on each of the six categories of the test, the comparison of the second posttest to the pretest did not completely yield the same results. On posttest 2, the categories of TK, TCK, and self-efficacy did not show a statistically significant improvement relative to the pretest. The results of these significance tests are included below in Table 7. However, the areas of TPK, TPACK, and level of technology integration did show a statistically significant increase. The lack of statistical significance also corresponded to descriptive decreases in the average score of participants in TK and TCK.

Table 7

Pretest Versus Posttest 2: Significance Test Results

	Mean Difference of Posttest 2 and Pretest (SD)	t (df)	*p*
TK	1.50 (8.75)	0.77 (19)	0.45
TCK	3.30 (9.60)	1.54 (19)	0.14
TPK	3.40 (6.35)	2.39 (19)	0.027
TPACK	8.10 (13.07)	2.77 (19)	0.012
SAMR	1.45 (2.61)	2.49 (19)	0.022
SE	2.80 (6.67)	1.88 (19)	0.076

Note: Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

Comparison of TPACK, Self-efficacy, and SAMR Components Using Linear Regression

Initially I had not planned to conduct regression analyses on the data. This was not included in the methods. However, I examined the data itself it seemed that there might be correlations present in the data. The adapted framework for this study also assumed that there was some relationship present between reported TPACK, self-efficacy, and the level of technology use as measured by SAMR. Within the modified TAM in chapter 3, TPACK was assumed to impact self-efficacy and the level of technology use. Self-efficacy was assumed to also impact the level of technology use. Thus, the logical course of action seemed to be to explore the relationships between the variables using the gathered data.

To explore these relationships, I conducted three separate bivariate regression analyses. The pairwise correlation between TPACK and self-efficacy was statistically significant ($r = .97$). This correlation coefficient would indicate a strong positive linear relationship between TPACK and self-efficacy. The slope of the regression indicated that for each unit increase of one point within the TPACK measurement self-efficacy scores increased by 0.57 points. Putting this into contextual perspective given the scales of TPACK and self-efficacy, this represents a 1.4% increase of self-efficacy score for every 1.3% increase in TPACK score. I calculated this by dividing the numerator and denominator of the slope by their respective score scales. Thus, while 0.57 points may seem like a small increase, it represents an approximately one-to-one relationship in increases in TPACK and self-efficacy.

TPACK and SAMR also demonstrated a statistically significant moderately strong positive linear relationship ($r = .76$). The slope produced by this bivariate regression analysis indicated that for each one-point increase in TPACK there was a 0.16 increase in the level of technology use reported by participants. To put this into perspective, given the scales of the SAMR and TPACK measurements, this increase would represent a score increase of 1.1%

increase in SAMR level reported per 1.3% TPACK score increase. Finally, the pairwise correlation between self-efficacy and level of technology use reported as measured by SAMR produced a statistically significant moderately strong positive correlation (r = .74). The slope of the model showed an increase of 0.27 points in score for the self-reported level of technology use for every one unit increase in the score of self-efficacy. Putting this into the perspective of the scales of SAMR and self-efficacy, for every 2.4% increase in self-efficacy score, SAMR increases 1.9% The results of the regression tests are presented below in Table 8.

Table 8

Results of Bivariate Regression T-test for Slope and Test of Significance of Pearson Correlation Coefficient for Posttest 2 Variables

Indep. Variable	Dep. Variable	Slope (SE)	t (df) (slope)	*p* (slope)	*r*	*t* (df) (r)	*p* (r)
TPACK	SAMR	0.16 (0.03)	4.99 (18)	<0.001	0.76	(18)	<0.01
TPACK	SE	0.56 (0.03)	17.69 (18)	<0.001	0.97	(18)	<0.01
SE	SAMR	0.27 (0.06)	4.60 (18)	<0.001	0.74	(18)	<0.01

Note: p-values for the significance test are presented for slope and the Pearson correlation coefficient “r”. Subscore categories are abbreviated for convenience. TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

While these tests were not originally planned in the data analysis procedures, they do have relevance for the study at hand. These results support the validity of the model that was used for the study. Each of the three primary components of the modified TAM were found to be statistically significantly positively correlated. These results further support the appropriateness of the aspects that were focused on in the PD design. Higher levels of TPACK correlated with higher levels of both self-efficacy and self-reported technology use. Higher levels of self-efficacy correlated with higher levels of self-reported technology use.

I then also examined the self-reported teacher technology use as a function of TPACK and self-efficacy. In this model, TPACK (b=0.19, 95% CI[-0.11, 0.48]) and self-efficacy (b=-0.04, 95% CI[-0.56, 0.47]) explained 58% of the variability in teacher self-reported level of technology use (r^2=.58, F(2,17)= 11.84, *p* <.001). The results of this multiple regression analysis indicate that TPACK and self-efficacy have a jointly statistically significant relationship with the self-reported level of technology use as measured by SAMR. Once again, this analysis was not a part of the initially planned data. However, these results support the validity of the initial model used for this study. The statistical significance of the relationship between the two primary inputs of the modified TAM and the desired output supports the theory that underpinned the PD design and the study as a whole. As will be discussed in the next chapter, the statistical significance of these results also have implications for future research.

Conclusion of the Research for Research Question 1

The first research question was as follows: What impact, if any, do focused technology-rich PD sessions have on improving mathematics teachers' self-perceptions of their TPACK, technology integration, and self-efficacy with respect to technology? This question can be answered by descriptive statistics and a matched-pairs *t*-test for the mean difference. Tables 7 and 8 previously given present an overview of the means, mean differences, and *p*-values for a two-tailed, matched-pairs *t*-test. In each case, the null hypothesis is assumed to be a mean difference of zero or that the two means are equal.

The previously discussed calculations support the conclusions of the study. Although the quantitative research question does not ask about correlation in linear or multiple regression, there is value in its discovery. These correlations give a partial confirmation that the three aspects that constituted the theoretical framework of this study showed statistically significant correlations with each other. The results of the multiple regression also suggest a correlation that confirms the value of the proposed modified TAM, which was assumed as a part of the theoretical framework. This result also provides potential suggestions for future research.

In summary, the results of the significance test show that focused technology-rich PD sessions produced an immediate improvement in the areas of TK, TCK, TPK, TPACK, and self-efficacy. The significance tests also showed that the PD sessions produced longer-term change in self-efficacy, TPACK, and some of the subdomains within TPACK. Relevant descriptive statistics confirm this conclusion. Thus, the results related to the first research question generally support the use of focused technology-rich PD sessions.

Research Question 2

Summary of Classroom Observations

First Observation: Participant 14

The first observation took place in a sophomore co-teach geometry course with participant 14. This observation was conducted with a teacher who had a pretest total score of 220 and a posttest1 score of 236. This lesson was a blended learning lesson focused on solving equations based on the properties of quadrilaterals. Technologies used included a smartboard, computing devices, and iXL. The highest level of technology use demonstrated was modification. The teacher demonstrated TPK at higher levels than TK and TCK. TPACK constituted teaching the content using technology and having students complete targeted practice using technology. Students functioned independently throughout most of the lesson and demonstrated the knowledge types of STK, SCK, and STCK as they showed an understanding of how to solve algebraic problems involving quadrilaterals and how to use technology for executing mathematical tasks

Second Observation: Participant 11

The second observation took place in a freshman algebra 1 course with participant 11. This observation was conducted with a teacher who had a pretest total score of 246 and a posttest1 score of 258. This teacher conducted a blended lesson pertaining to graphing linear equations. By using technologies like iPads, a document camera, and Desmos the teacher demonstrated a level of technology use of modification. The teacher nicely demonstrated TK, TPK, TCK, and TPACK equally as they connected the content to Desmos, used the instructional strategies of modeling and an I do-You do-We do gradual release of responsibility, and allowed students to be in the driver seat of their learning through exploration. The quality of the TPACK allowed the lesson to be conducted at a level in which students led their instruction both individually and collaboratively as they worked through the problems which led to students demonstrating SCK about linear equations, STK about using Desmos, and STCK about using Desmos to graph and analyze linear equations.

Third Observation: Participant 12

The third observation also took place in a freshman algebra 1 course with participant 12. This observation was conducted with a teacher who had a pretest total score of 218 and a posttest1 score of 250. This teacher's topic was the same as that of the second participant. The teacher chose to use the TI-Nspire calculator instead of Desmos. The more robust benefits of using Desmos to graph were removed due to the limit in functional capability of the type of linear equations that can be plugged into the calculator. Thus, technology was reduced to a level of augmentation. TK, TCK, TPK, and TPACK were each more limited than the previous observations due to their choice of technology. STK, SCK, and STCK were shown as some students used calculator functions to complete mathematics problems and check work. However, it was also noteworthy, that less of the students were engaged in using technology in this lesson than during the comparable lesson previously observed. This is perhaps due to the more limited functionality of the technology chosen.

Fourth Observation: Participant 1

The fourth observation took place in a senior algebra 2 course with participant 1. This observation was conducted with a teacher who had a pretest total score of 205 and a posttest1 score of 266. The topic being explored during the lesson was transforming absolute value functions. The lesson took place on the day of the test review. Thus, the lesson was cumulative in the nature of its content. The classroom scenario was a blended learning scenario. The teacher exhibited a level of augmentation by using a hyperlinked PowerPoint presentation to review concepts with students. The teacher demonstrated TK, TCK, TPK, and TPACK equally throughout the lesson. This lesson was a teacher-driven lesson. SCK was demonstrated as students showed their understanding of content. STK was limited due to the prevalence of a passive level of technology interaction on their part. Finally, as a result of the convergence of these two, STCK was also demonstrated to be limited because students did not necessarily demonstrate an ability to execute significant mathematical operations using the graphing technologies present.

Fifth Observation: Participant 16

The fifth observation took place in an Advanced Placement computer science course with participant 16. This observation was conducted with a teacher who had a pretest total score of 255 and a posttest1 score of 272. This course is unique in that the majority of the work students would encounter naturally occurs at the modification and redefinition levels. Given that this is a course in computer science, it is reasonable to assume that students would consistently execute work that goes beyond that which could be easily done without the technology. This was confirmed as students used coding software to create random password generators. The teacher was very much hands-off and a facilitator. TK, TCK, TPK, and TPACK were robustly shown as the teacher understood how to use strategy specific to the computing software to facilitate the learning of creating applied algorithms in this scenario. Students demonstrated each type of their knowledge as they led their own learning to use the software to apply the algorithm programming techniques

Sixth Observation: Participant 4

The sixth observation took place in an on-level statistics course with participant 4. This observation was conducted with a teacher who had a pretest total score of 240 and a posttest1 score of 267. The topic of the lesson in this statistics course was representing data descriptively through a least squares regression line. Multiple instances of technology use were present. The lesson itself was highly creative in its approach. The lesson also demonstrated a level of student interaction in which students had significant control over the lesson and the teacher acted in a facilitation role without directly influencing the students beyond the level of assistance. Video technology and calculators were used at the redefinition level. The teacher equally and dynamically demonstrated TK, TCK, TPK, and TPACK as the teacher used technology to create a higher level thinking the task in which students discovered aspects of modeling with linear regression. SCK, STK, and STCK were equally dynamic as student led their learning through experimentation using technology.

Seventh Observation: Participant 13

The seventh observation took place in an on-level precalculus course with participant 13. This observation was conducted with a teacher who had a pretest total score of 221 and a posttest1 score of 209. This participant was one of two who showed a decrease in overall score between the pretest and posttest1. In this class the subject was writing and graphing quadratic functions. The teacher also used iXL at the level of modification. TPK was demonstrated less than TCK and TK in this lesson due to the lack of use of certain key features of iXL. This also resulted in a lower level of TPACK shown. SCK, STK, and STCK were shown as students used computing and calculating devices to execute mathematical and educational tasks. However, these knowledges were also more limited when compared to other observations with similar technologies.

Eighth Observation: Participant 18

The eighth observation took place in an on-level geometry course with participant 18. This observation was conducted with a teacher who had a pretest total score of 165 and a posttest1 score of 200. This lesson was similar to the first classroom lesson observed in that it was also a blended learning lesson focused on solving equations based on the properties of quadrilaterals. iXL was once again used at the level of modification. A few students also used a TI-Nspire calculator to assist their computations. TCK was demonstrated less than TK and TPK. Beyond using iXL, students did not use technology much for mathematical operations beyond what could have been easily achieved without the calculator. Thus, STK and STCK were lower than SCK.

Ninth Observation: Participant 20

The ninth observation took place in an on-level algebraic reasoning course with participant 20. This observation was conducted with a teacher who had a pretest total score of 223 and a posttest1 score of 217. This participant was the second of two who showed a decrease in overall score between the pretest and posttest1. The topic of this lesson was linear equations. The teacher used a Desmos Marbleslides activity at the level of redefinition to facilitate a student-led exploration of graphing transformations of linear functions. Through the teacher's modeling, assistance, and facilitation, they demonstrated equally high levels of TK, TCK, TPK, and TPACK. Because of the independence shown by students and the level of their work, SCK, STK, and STCK were shown as students understood teach themselves by exploring how to graph and manipulate linear equations using the features of the Desmos graphing platform.

Results of Research Question 2

The second research question was as follows: After the participants attended focused technology-rich PD sessions, what evidence of TPACK and level of technology integration was observed during a technology-rich lesson? This question was directly answered by the nine classroom observations conducted. The qualitative data were analyzed using coding. Within any classroom teaching session, numerous nuances and classroom environments can lead to analysis paralysis. Thus, it was necessary to focus on the most vital descriptive aspects relevant to the problem at hand. The theoretical framework described in chapter 3 provided the key to selecting relevant codes for the data.

The second research question was directly tied to two of the three components of the combined theoretical framework—namely, teacher knowledge and level of technology use as measured by the SAMR scale. The observation document was also exclusively tied to these two aspects. The third aspect, self-efficacy, was measured by the pretest and posttests and lies outside the scope of this question. Thus, codes relevant to teacher knowledge and level of technology use were selected. These codes were: TK, TCK, TPK, TPACK, and SAMR level. These codes can be categorized in two ways: Teacher knowledge and level of technology use.

Teacher Knowledge

The first qualitative component of teacher knowledge was demonstrated through TPACK. Each of the observed teachers (n = 9) clearly demonstrated an element of thoughtful TPACK in their instruction. For example, the first observation TPACK was displayed through teaching the content using technology and having students complete targeted practice using technology. Another teacher demonstrated TPACK holistically as the teacher demonstrated how to engage students in a review activity directly aligned with a specific topic, namely graphing the transformations of absolute value functions. The results regarding the individual subdomains of TPACK, including TK, TCK, and TPK, were mixed. Most of the observed teachers demonstrated TPK most strongly among the three. For example, in the first observation TPK, was nicely demonstrated as the teacher taught and facilitated student practice using technological assets. In the fifth observation, TPK was also present as the teacher shared strategies for using the software and demonstrated an understanding of how to use the technology and the lesson content to create a problem-based learning scenario in which students were asked to create a generator given certain parameters. Other examples of TPK included understanding how to use technology to strategically assess and facilitate student practice. Two teachers used a graphing utility to enable a self-guided exploration of graphing linear functions. Others used technology to provide students with adaptive learning through the iXL platform.

TCK and TK were more limited in these observations. While they were technically present in each observation, the degree to which they were demonstrated was lower than TPK in five of the nine observations. For example, in the first observation TCK was limited as the knowledge demonstrated related more to the pedagogy involved as opposed to actually executing mathematical content actions using technology. In the third observation, TCK was shown through the teacher's knowledge of using the calculator to graph lines. Yet, this was limited as the teacher did not actually model the calculator use for the class and instead only answered questions as the students had issues. One reason why TCK and TK might have appeared less strong was the independence demonstrated by the students and allowed by the teacher. The teachers offered less direct instruction and instead favored more hands-on learning models such as discovery-based or project-based learning, which contribute to a higher level of TPACK and technology integration. TCK and TK were seen more indirectly as teachers demonstrated their knowledge by virtue what would have been needed in preparation in order to facilitate the lesson. For example, one participant used a PowerPoint presentation with hyperlinks for a game that would have required the demonstration of TK outside of the instructional time. As demonstrated by this example, many of the lessons could not have been plausibly planned or executed without the role played by TCK and TK behind the scenes. In other words, the lower demonstration of TCK and TK throughout the observations was not necessarily detrimental in the overall teaching and learning process.

Thus, in answer to the research question, we can conclude that after attending technology-rich PD sessions, teachers explicitly demonstrated TPACK and TPK. They also explicitly demonstrated TK and TCK in a less robust manner than TPACK and TPK but implicitly demonstrated high levels of it by virtue of the quality and dynamics of their lesson.

Level of Technology Use

The nine observed lessons were characterized by demonstrations of three of the four levels of SAMR. The lowest possible level of technology use was not the peak level of technology use demonstrated by any of the teachers. Two of the nine teachers attained the second level (augmentation), four exhibited modification, and three demonstrated the highest level of technology use possible (redefinition). The two teachers who attained the level of augmentation used a teacher-led technology-based PowerPoint to review concepts or a TI-Nspire calculator as a limited supplement. Both of these demonstrated a direct substitution with functional improvements (Puentedura, 2003). Four teachers used technology at the level of modification. It is interesting that three of the four teachers at this level used the iXL platform. It was noted in the first chapter that using iXL during lessons has been one of the major initiatives within the school district. The use of iXL in this context constitutes a modification level use of technology on the SAMR scale. iXL is a unique platform that goes beyond solving problems. iXL offers leveled problems and adapts to the needs of students based on their performance. Thus, students are given an adaptable sequence of problems that adjusts in difficulty and repetition to help them achieve success. The iXL platform also allows teachers to use a dashboard to monitor students in real time. The observed teacher chose to use this during class and was able to monitor students in order to keep students on task and to step in to help students stuck on a particular type of problem at a certain level. Thus, the iXL platform went beyond substitution with functional improvement to allow for significant modification of the task in a manner that still could have been completed without the technology (Puentedura, 2003). The remaining teacher used Desmos to allow students to explore converting different equations of linear equations from standard form to slope-intercept form. The final level of redefinition was uniquely demonstrated through three very different lessons. Each of these lessons demonstrated technology being using in a manner that would have otherwise been impossible or implausible without the technology (Puentedura, 2003). One observation involved students using Desmos to graph through a Marbleslides activity. As they went through a self-paced lesson they experimented with the shapes of graphs and the impacts of transformations on them. Another teacher used video technology to help students generate precise data from an experiment. The final teacher used computer coding software to allow students to work through a cumulative application project in which they were programming the code for random password generators. The desired levels were modification or redefinition. It is also unique to note that these examples of modification and redefinition each occurred concurrently with a model in which students were self-directed and allowed to discover concepts through exploration. As I pointed out in chapter 2, the highest level of technology use is not always feasible, so both of these levels are considered as representing advanced technology use. Therefore, after attending two focused PD sessions, seven of the nine observed secondary mathematics teachers at High School X demonstrated the ability to deliver and facilitate technology-rich lessons that included higher levels of technology use.

Conclusion for Research Question 2

Overall, with regard to the second research question, the examination of teacher knowledge showed that TPACK and TPK were demonstrated. TK and TCK were demonstrated in a more limited fashion but can be inferred through qualities present in the lessons that would have necessitated the application of TK and TCK. The ranking of lesson technologies showed that seven of nine observed teachers demonstrated the use of technology at the desired levels of modification and redefinition. Therefore, overall, TPACK, its subdomains, and the level of technology use were sufficiently shown in desired amounts after teachers attend focused technology-rich PD sessions. This finding provides initial evidence in favor of the use of focused technology-rich PD sessions.

Research Question 3

The third research question was as follows: After attending focused technology-rich PD sessions, how do the self-perceptions of teachers compare to what is observed during a technology-rich lesson? This question can be answered by comparing the results of the pretest and posttests to what was observed of each teacher during their technology-rich lesson. A comparison of the breakdown of individual scores to individual observations is also relevant in answering this question. Table 9 presents the individual scores on each test by participant and the highest level of technology use observed during the classroom observation. Figures 8, 9, and 10 present a graph of each observation participant's scores in the subscore categories of TPACK, level of technology use (SAMR), and self-efficacy correlated to their highest level of technology use observed.

Table 8

Individual Subscores of Participants on Pretest, Posttest 1, and Posttest 2 with Highest Level of Technology Observed

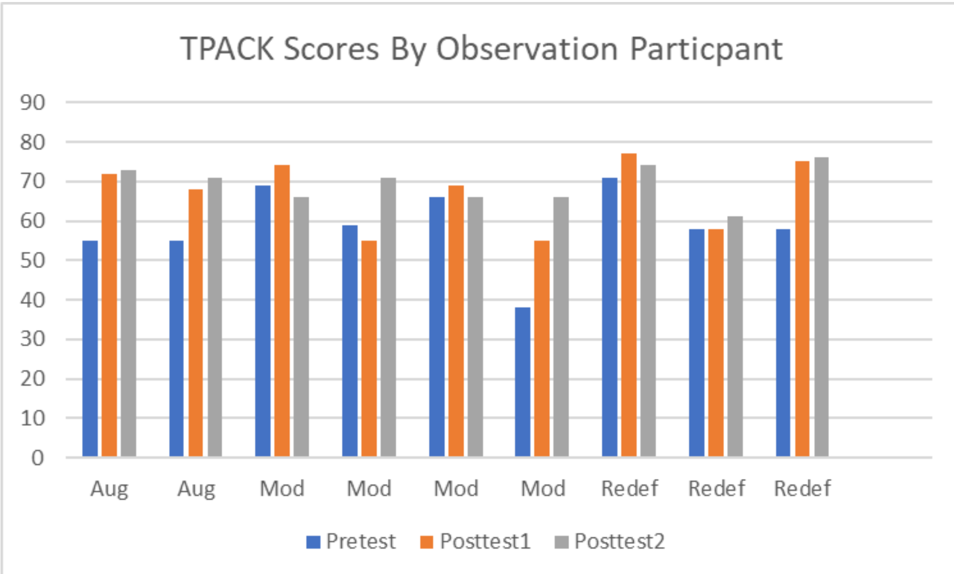
			Participant								
Category	Scale	Test	1	12	11	13	14	18	4	16	20
TK	49	Pretest	37	38	44	38	34	37	43	48	43
		Posttest 1	46	47	46	40	36	37	45	49	40
		Posttest 2	41	46	46	46	32	42	46	48	40
TCK	56	Pretest	41	42	51	47	37	34	50	54	45
		Posttest 1	54	51	51	45	43	38	53	56	47
		Posttest 2	51	48	48	50	44	48	55	52	47
TPK	42	Pretest	29	35	38	35	36	22	40	38	34
		Posttest 1	40	36	38	33	38	30	41	42	31
		Posttest 2	41	42	36	39	36	36	42	40	36
TPACK	77	Pretest	55	55	69	59	66	38	58	71	58
		Posttest 1	72	68	74	55	69	55	75	77	58
		Posttest 2	73	71	66	71	66	66	76	74	61
SAMR	14	Pretest	11	12	6	10	11	8	10	5	8
		Posttest 1	13	12	10	7	11	10	12	6	6
		Posttest 2	14	12	10	8	11	12	14	10	9
SE	42	Pretest	32	36	38	32	36	26	39	39	35
		Posttest 1	41	36	39	29	39	30	41	42	35
		Posttest 2	42	36	35	41	36	36	42	42	35
Highest Level of Technology Use Observed			Aug	Aug	Mod	Mod	Mod	Mod	Red	Red	Red

Note: Levels of SAMR are abbreviated for convenience. Aug: Augmentation; Mod: Modification; Red: Redefinition. Subscore categories are abbreviated for convenience. TK: Technology Knowledge; TCK: Technology Content Knowledge; TPK: Technology Pedagogy

Knowledge; TPACK: Technology Pedagogy and Content Knowledge; SAMR: Substitution, Augmentation, Modification, Redefinition; SE: Self-efficacy.

Figure 8

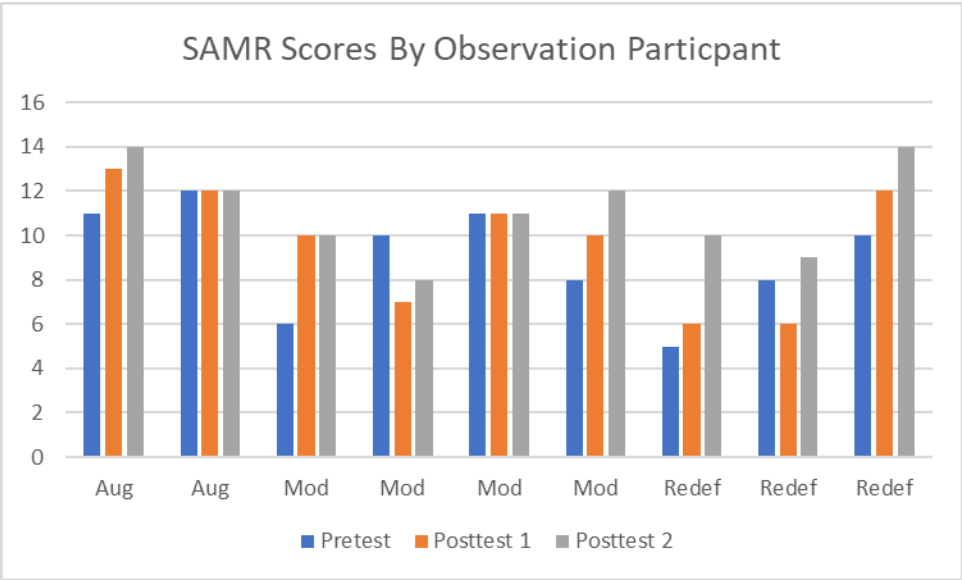
TPACK Scores by Observation Participant with Highest Level of Technology Observed



Note: Levels of SAMR are abbreviated for convenience. Aug: Augmentation; Mod: Modification; Red: Redefinition

Figure 9

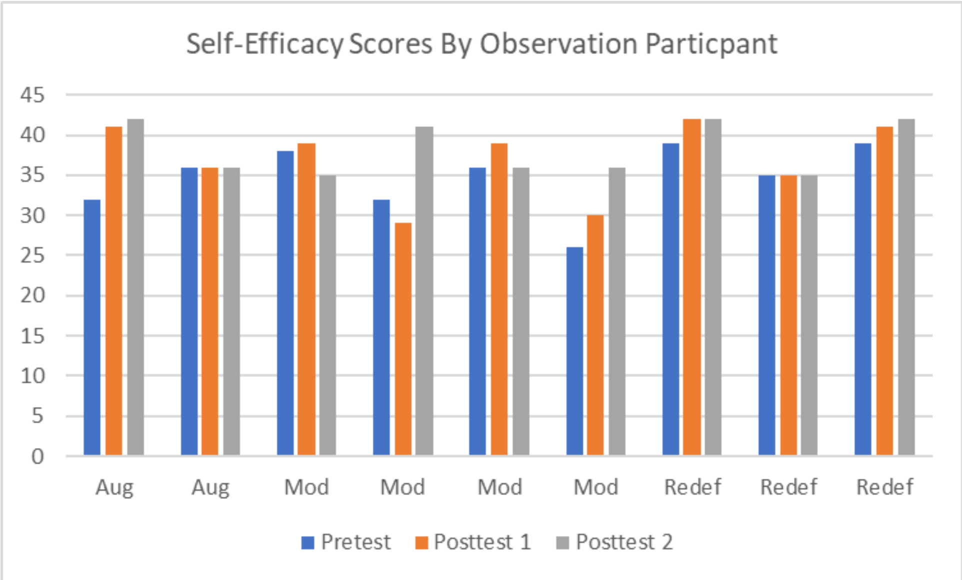
SAMR Scores by Observation Participant with Highest Level of Technology Observed



Note: Levels of SAMR are abbreviated for convenience. Aug: Augmentation; Mod: Modification; Red: Redefinition

Figure 10

Self-efficacy Scores by Observation Participant with Highest Level of Technology Observed



Note: Levels of SAMR are abbreviated for convenience. Aug: Augmentation; Mod: Modification; Red: Redefinition

Comparison of Reported TPACK to Observed TPACK

One of the most striking comparisons is in the subdomains of TK and TCK. The results related to the first research question showed that statistically significant increases in TK and TCK were not demonstrated in the second posttest. The results of the second research question demonstrated that the knowledge subdomains of TK and TCK were less visible during the classroom observations. Interestingly, of the nine teachers observed, eight of the nine teachers increased their TK score from the pretest to posttest 2, and only seven of the nine teachers increased their TCK scores from the pretest to posttest2. However, relative to the pretest, the overall increase was smaller in the second posttest and was lower than the average scores in the first posttest. If the evidence given in the trends is to be believed in this case, then it seems that the focused PD sessions were not as impactful on the subdomains of TK and TCK. This finding could be due to the focus of the content and could indicate changes needed in future focused PD sessions.

The areas of TPACK and TPK were more largely demonstrated. This finding corresponded to overall score increases on both posttest 1 and posttest 2 that proved to be statistically significant. Eight of the nine participants showed increases in TPACK and TPK from the pretest to the second posttest. TPACK was also the second-highest area of change in the posttest results. On a scale of 77 possible points in the TPACK subdomain of the pretest and posttest, the observed participants scored themselves between 61 and 76 total points, or between 79% and 99%. TPK showed even more promising individual results of between 36 and 42 points on a scale of 42, or a range from 86% to 100%. This corresponded to a noted strength in the observations of the nine participants related to the second research question.

Because of the nature of the data collected, a qualitative cause-and-effect determination is not possible. However, comparing the teachers' self-perceptions to the other findings does provide relevant implications regarding the success of the focused PD sessions. Within this smaller sample, as indicated by Figures 7-9, it seems evident that the teachers' self-reports closely match what I observed during the technology-rich lessons.

Comparison of Reported Level of Technology Use to Observed Level of Technology Use

The secondary mathematics teachers observed during the technology-rich lessons used technology largely for teaching and learning at the levels of modification and definition. As indicated in Table 8, only two of the nine participants used technology at the second-lowest level, augmentation. None of the teachers used technology at only the lowest level of substitution. The pretest and posttest results were also very positive in this area. The level of technology use self-reported by teachers was the highest category of change on both posttests. Again, it appears that the self-reports and observations align closely in confirming improved levels of technology use.

Overlap of Reported Level of Technology Use, Observed Level of Technology Use, and Self-efficacy

The overlap of the various portions of the pretest, posttests, and observations provides interesting insights into the possible interaction between the three primary aspects of the theoretical framework. This overlap also aligns with the linear and multiple regression correlations that were calculated in the results of the second posttest data in the first research question above. First, it was previously noted that the change in self-reported self-efficacy remained consistent from posttest 1 to posttest 2. Self-efficacy was scored on a scale of 42 possible points and included scores ranging from 35 to 42, or 83% to 100%. The teachers with rankings of augmentation had scores of 36 and 42. Those with rankings of modification had scores of 35, 36, 36, and 41. Those with rankings of redefinition had scores of 35, 42, and 42. Two of the three individuals who were observed using technology at the level of redefinition and one of the two individuals at the lower level of augmentation had perfect scores on this measure, indicating complete self-efficacy regarding technology use in instruction as measured by this instrument. One may question whether this self-efficacy was directly tied to the two focused PD sessions. Without a separate observation instrument beyond the scope of the present project, this cannot be conclusively determined. However, the quantitative results did show score ranges from 83% to 100% in this subsection. Self-efficacy was high overall, with both consistent and statistically significant change.

The overlap between TPACK and level of technology use is interesting as well. TPACK was scored on a scale of 77 and included scores ranging from 61 to 76, or 79% to 99%. The observed teachers with rankings of augmentation had scores of 71 and 73. Those with rankings of modification had scores of 66, 66, 66, and 71. Those with rankings of redefinition had scores of 61, 74, and 76. These scores once again indicate the need for additional research on the relationship between TPACK and self-efficacy. The regression analysis results indicated a strong positive linear relationship between increases in teacher knowledge through TPACK and teacher self-efficacy. I previously noted the statistically significant positive correlation between these two factors from a quantitative perspective. Additional observations from a qualitative perspective would be needed to further investigate and explain the correlation. Is there perhaps an underlying causation present? More on the needs of future research is explored in chapter five.

Comparison Between the Level of Technology Used, Teacher Knowledge Levels and Types, Student Technology Levels and Types, and Lesson Design

As was previously discussed, teacher scores on the respective sections of the pretest and posttests corresponded to what was observed about their knowledge during the lesson. Higher levels of technology use and knowledge were also found quantitatively through regression analysis and qualitatively through analysis to correlate to higher levels of reported self-efficacy. When comparing the lesson design to the level of technology use, level of teacher and student knowledge, and corresponding level of self-efficacy an additional trend emerged. The lessons with a higher level of technology use always took place in lessons with a design favoring self-led student exploration of the topic using technology as the means of exploration. This was present in all three situations of redefinition and all four situations of modification. Students led their learning. They demonstrated equal levels of SCK, STK, STCK. Teachers facilitated learning. They demonstrated higher levels of TPACK. With one exception, they also demonstrated higher levels of TK, TCK, and TPK simultaneously. The metrics used in this study cannot determine causality. Yet, the correlation of these is undeniable and significant for practice.

Conclusion for Research Question 3

In the comparisons of reported and observed knowledge, there was close agreement between the quantitative and qualitative data that TPACK and TPK were demonstrated and that TCK and TK were not as readily observed. The mixed-methods results confirm quantitively and qualitatively that teachers' self-reports on their level of technology use to facilitate teaching and learning matched what I observed during the technology-rich lesson. This alignment provides some corroboration that the increases, benefits, and positive attributes of the PD sessions and observations can be trusted as accurate.

Overall Conclusions

The three research questions represented an inquiry into the impact of focused PD sessions on improving key aspects relating to teacher use of technology use in secondary mathematics. The posttests showed increases in each of the three categories deemed integral to successful technology use in instruction. Teacher TPACK, level of technology use, and self-efficacy regarding technology each increased as a result of the administration of the two PD sessions. The observations showed that the majority of teachers competently used technology in classroom learning at the desired levels of modification and redefinition. The observations also showed the presence of TPACK and its subdomains. TPACK and TPK were more strongly observed, but TCK and TK were also present. The qualitative and quantitative results were mutually corroborating. Therefore, it can be concluded that focused PD sessions have the potential to improve key aspects related to teachers' technology use in secondary mathematics instruction.

Interaction Between the Research and the Context

How the Context Impacted the Research

The context impacted the research and the design of the professional development. Going into the project, I examined the PD initiatives that had previously taken place on campus. Because preceding initiatives had been limited to one or two short sessions, I determined that a more limited scope of professional development was appropriate for this context. However, as discussed in chapters 2 and 3, research supports the viability of both short- and long-term PD initiatives.

The context also impacted the sample size for two reasons. First, the department currently has 23 teachers, so the potential sample was limited to 23 math teachers at a single school. This fact may limit the transferability of the results to other school contexts. However, this sample did completely represent the context of the established problem of practice. Second, three teachers did not complete the study, as they missed one or both PD sessions due to illness or sudden maternity leave. However, these three teachers had similar teaching experience, teaching areas, and pretest scores to other participants. Thus, the diversity of the sample participants was not necessarily reduced.

A final limitation exists in the voluntary nature of the observations. I had expected that more participants would agree to be observed. My goal was to choose between four and nine observation subjects from a larger set. However, only nine subjects volunteered. Nevertheless, this group still represented a significant variety of participants. When the pretest and change in posttest scores were compared to each other, the nine participants contained the full spectrum of low and high pretest scores as well as low and high changes in scores. Thus, the intent of the selection process was honored, and the results were not noticeably diminished in value.

Operationally, the study was executed with optimal success. There were no difficulties in scheduling the PD sessions or the observations. The goals set for the timelines of PD implementation and observations were fully met. The department and school leadership were very supportive of the project. Thus, there were no contextual factors that diminished or impacted the project negatively.

How the Research Impacted the Context

The research was positively received in the local context. A few immediate impacts were noted. The departmental leadership took the supplemental resources and attachments provided during the PD sessions and included them as a part of the planning time for team-level meetings. This material has specifically been used within the local context to impact how the secondary mathematics teachers design lessons within the theoretical frameworks used for the study. The PD sessions themselves were very well received within the department and by departmental leadership. As a result, the department's leaders have recommended implementing these PD sessions with math teachers at the district's other three high school campuses. Additionally, departmental leadership has proposed during schoolwide leadership meetings that a modified version of the training be developed for the purpose of applying the content to other disciplines within the school. The recommendation to train each department using this modified PD framework has also been presented to the campus administration. Finally, interest was generated among teachers who are members of a statewide professional organization for innovative teachers in Texas. As a result, this organization has asked to have the same training offered virtually to teachers throughout the state. Thus, the results have been very positive and indicate a tremendously warm reception of the focused PD content.

Summary

This study applied a mixed-methods approach. The pretest and posttests were analyzed with descriptive statistics, linear regression, and significance testing. The results showed a statistically significant increase in self-reported self-efficacy, level of technology use (as measured by the SAMR scale), and TPACK and some of its subdomains after secondary mathematics teachers at High School X attended focused PD sessions. Qualitatively, the data were examined through creating codes based on the established theoretical framework that underpinned the study. TPACK and some of its subdomains were clearly observed during a technology-rich lesson. The desired levels of technology use were also demonstrated by seven of the nine participants. Performance on the two subdomains of TK and TCK were weaker both in terms of change on posttest2 and in the observations. However, the observations confirmed a sufficient presence of TPACK and TPK. The comparison of self-reported technology capacity to observed technology use found that the two were closely aligned. The results of the study support the use of focused PD sessions to improve the quality of technology use in secondary mathematics classrooms at High School X by strengthening teachers' TPACK, technology integration level, and self-efficacy with respect to technology.

CHAPTER V: DISCUSSION

Summary of Findings from Chapter 4

After secondary mathematics teachers at High School X attended focused PD sessions, results from the pretest and posttests showed a statistically significant increase in self-reported self-efficacy, level of technology use (as measured by the SAMR scale), and TPACK and some of its subdomains. Effective application of TPACK and some of its subdomains was clearly observed in numerous teachers during a technology-rich lesson. The SAMR levels of modification and redefinition were demonstrated by seven of the nine participants. A comparison of the qualitative and quantitative results further confirmed the presence of TPACK and TPK. The results of this study generally supported the use of focused PD sessions as a means of improving the quality of technology use in secondary mathematics classrooms at High School X. The evidence indicates that such sessions can improve teachers' TPACK, technology integration level, and self-efficacy with respect to technology.

Discussion of the Results in Relation to Extant Literature

The results of this study aligned with the existing literature. First, prior researchers have confirmed that PD can be used as a means of intervention to help teachers grow in their practice. For example, the seminal work of Loucks-Horsley et al. (2010) found many possible benefits of using PD as a means of initiating change in mathematics education. These results are also aligned with the findings of Gómez-Blancarte and Miranda (2021).

The results more specifically showed a positive relationship between the use of PD as an intervention and improvements in TPACK. Teacher knowledge was a major component of both the theoretical framework and the PD session content. Similarly, Driskell et al. (2018) specifically linked the use of professional development in mathematics education to the aspects of TPACK (Koheler & Mishra, 2009) and the Comprehensive Framework for Teacher Knowledge (CFTK; Ronau & Rakes, 2012).

By virtue of its success, this study also corroborated the attributes of effective PD that were discussed in the literature review. Firstly, this study was highly contextualized to the needs of the participants. Avci et al. (2019), Darling-Hammond et al. (2017), Bates and Morgan (2018), and Lo (2021) each identified such contextualization to be a primary consideration in effective professional development. The benefits of a hands-on design in PD were also evident in the work of Liao et al. (2017). Although I did not measure teacher engagement formally during the PD session, informally I observed that teachers were engaged actively through hands-on participation and peer collaboration when placed in collaborative small groups based on their primary teaching focus. My findings align with the learner-centered, active learning, and collaboration aspects of PD proposed by Avci et al. (2019), Bates and Morgan (2018), Darling-Hammond et al. (2017), and Lo (2021).

Whereas the components of successful PD initiatives are robustly agreed upon, the desirable duration and frequency of PD sessions remains a matter of discussion. Avci et al. (2020), Bates and Morgan (2018), Darling-Hammond et al. (2017), Lo (2021), and Loucks-Horsley et al. (2009) proposed using extended or sustained-duration PD initiatives to effect change. The seminal work of Loucks-Horsley et al. (2009) even proposed using multi-year PD initiatives to produce continual growth. Yet, Lydon and King (2009) disagreed with this approach, noting the frequent lack of teacher interest in long-term PD. They suggested that even single sessions of PD could produce beneficial change. My study did not seek to compare long-term and short-term PD initiatives. The results of my study certainly do not contradict the benefits of long-term PD initiatives; addressing that question would be beyond the scope of the project. My study does, however, lend credence to the claims of Lydon and King (2009) in that this short-term PD initiative produced desired change in the participants.

Finally, the success of the study aligns with what was expected from the combined theoretical frameworks. Building on the seminal work of Davis (1985), Joo et al. (2018) used the TAM to tie self-efficacy and TPACK directly to classroom technology use. The success of the PD model adopted in my study showed the complementary nature of these components. Furthermore, the regression analyses I conducted showed that self-efficacy and TPACK were positively correlated with each other and together were correlated positively with increases in the level of technology use reported.

Discussion of Personal Lessons Learned

The first lesson I learned in this project concerned the nature of volunteerism. I had originally planned to select observation subjects from a larger pool. Initially, I anticipated that at least two-thirds of the teachers in the department would volunteer to be observed, as observations are conducted somewhat more frequently than in previous years. However, only nine out of twenty people volunteered to be observed. The selection criteria I had originally established assumed a wider representation of teacher volunteers. Fortunately, the nine who volunteered were in fact a fulfillment of that goal as they themselves represented a variety of combinations of pretest scores and pretest/posttest score changes

Another lesson was the value of establishing a window of time for completion of posttest surveys. The second posttest was conducted at the end of a nine-week period. As a result, it was not administered in the immediate context of a face-to-face interaction like the previous surveys. The time needed for teachers to complete this should not be viewed as a lack of participation or interest on their part. Rather, given the enormous responsibilities placed upon teachers and their incredible dedication to their work, their time schedules fill up quickly. Having this natural organization preplanned allowed me to collect the final posttest surveys in a timely manner.

Implications for Practice

The primary implication for practice demonstrated in this study is the potential of focused PD to positively impact how teachers use technology in the classroom. The study's framework centered on teacher knowledge and self-efficacy as means to improve teacher practice. This study also used PD sessions that were limited in length. Often, a concern in implementing any new PD initiative is the ongoing additional work required in a more sustained model. This study showed that using a smaller scope in terms of frequency of PD sessions produced change that was then sustained in each of the three primary desired areas. A problem-solving approach based on the scientific method was used in formulating and conducting this study. Thus, my results possibly indicate that practitioners who are responsible for training teachers should use a problem-solving approach based on the scientific method to design smaller targeted PD sessions to improve teacher knowledge and self-efficacy.

A second implication for practice relates to the components of successful PD sessions. Key attributes of successful PD sessions include a focused design to meet specific needs of the participants, active collaboration among participants, and interaction with real content that participants would likely deal with in the scope of their jobs. Each of these components was heavily integrated into the design and delivery of the PD sessions. Although this study did not specifically measure PD session design, the fact that the PD sessions were successful in creating the desired change in the target population indicates the effectiveness of the components used as a guideline for the creation and implementation of the PD sessions. These components should also be considered by individuals responsible for creating and implementing PD sessions within the secondary mathematics context.

A final implication involves the nature and focus of teacher training. Although this study was conducted in a secondary education setting in which the participating teachers had at least one year of experience, it could also have implications for practice for university-based and alternative teacher training programs. Regardless of the discipline or grade level, all teachers today must know how to use technology effectively. Teaching and learning have become saturated with technological applications. Teacher training must focus on training teachers to be PD leaders. This must be a primary focus of both preservice and ongoing teacher training and not a secondary consideration. The theoretical framework developed as the foundation of this study could equally be applicable to training preservice teachers. It could also provide a framework for training newly hired teachers within school districts.

Lessons Learned

Professionally, by conducting this study I have learned multiple lessons. The benefits of the research-based PD design components were highly significant and transformative. In an effort to align with these aspects, I designed the PD sessions using suggestions from prior researchers to involve minimal direct instruction and lecture. Instead, I created active and collaborative learning experiences for teachers. To suit the local context, I also designed the lessons to include components of pedagogy aligned with the most recent initiatives within the math department. These included the use of rotations, gallery walks, and vertical nonpermanent surfaces. This design was, in part, based on a recent book study completed by several members of the department. Aligning with the methodology and pedagogy being used in a departmental initiative allowed the PD sessions to align more closely into the natural progression of back-to-school events. Instead of two stand-alone events, my PD sessions felt like a part of the greater whole.

Through this study I have also demonstrated the value of targeting professional development to specific needs. As previously discussed, I conducted my doctoral internship in this same department. A large part of the internship involved observing teachers and determining their needs. I also initiated a preliminary needs assessment during the internship, interviewing both teachers and department leaders. This assessment provided the pilot data and determined my context for the PD sessions. Having these data points allowed me to focus on real needs as opposed to presumed needs. Had I not executed this step in advance of my ROS study, the PD sessions may not have been as successful. The valuable lesson here is that personalization is always preferable when possible.

Recommendations

This study provided multiple potential implications for future research. As a secondary exploration within the quantitative analysis described in Chapter 4, I conducted a series of significance tests on the correlation of variables, within both a linear regression and a multiple regression context. These correlations did correspond to the findings of existing literature (Driskell et al., 2018; Gómez-Blancarte & Miranda; 2021) within the field. Yet they also indicate the need for additional research dedicated to the relationship between the components that intersect with how teachers use technology within the facilitation of teaching and learning in their classrooms.

The results from the multiple regression analysis also suggested a potential initial confirmation of the adapted TAM presented in Chapter 3. Both knowledge and self-efficacy were positively correlated with the level of technology use. There was a statistically significant correlation with knowledge and self-efficacy impacting the level of technology use. This is only an initial suggestion. Additional research should be conducted to fully explore the implications of these preliminary results. Might there be a larger unifying theoretical framework that encompasses each of these aspects in a holistic manner? Are there additional aspects that should be considered in designing a complete framework? Future research could provide an even clearer path forward for practitioners, given that the paradigm shift toward technology use is not likely to diminish at any time in the future.

It was also interesting that scores on two of the subdomains of TPACK decreased from the first posttest to the second posttest. A more extensive longitudinal study could include additional posttests, to determine how the levels of knowledge, technology use, and self-efficacy change over a longer period of time following attendance at focused, technology-driven PD sessions. Might it be that the levels decreased due to a lack of reinforcement? Did the intersection of practice and training lead teachers to perceive themselves as more deficient? Did the training lead teachers to consider that they still had more to learn on the subject to be proficient?

Also, a future study could compare similar groups of teachers who use similar curricula but receive PD sessions of different durations. A school district like the one evaluated in this study would provide an optimal environment, as there may be multiple high schools using the same curriculum. Does the frequency or duration of PD effect the ability to produce sustained, long-term increases in teacher knowledge, level of technology use, and self-efficacy? In the literature review, it was noted that various studies (Darling-Hammond et al., 2017; Lo, 2021; Loucks-Horsley et al., 2009; Lydon & King, 2009) have presented conflicting evidence on the desirable PD duration. Research on this question could have highly practical implications for schools across the nation.

It would also be fascinating to extend the theoretical framework deployed here to map out effective technology use to other disciplines within secondary and perhaps even primary education. The original studies examined that make up the theoretical framework were not necessarily discipline-specific, i.e., relevant only to the field of mathematics. Therefore, they should also have merit for other disciplines. What impact would the combination of the factors contained in the theoretical framework have in other disciplines? Are there differences in how this training would impact the areas of English, science, and social studies as compared to its impact on secondary mathematics teachers? Furthermore, are there differences in how this study and its components would impact primary teachers as opposed to secondary teachers? Each of these questions could generate research studies that would have additional practical implications regarding how technology implementation use can be improved within teaching and learning at every level of the education system.

The theoretical framework of this study also offers implications for teacher training programs. How do existing university-based, alternative, and in-district programs train new teachers to effectively use technology? How does the theory of practice align with the theory of training? Do new teachers feel they have the knowledge and self-efficacy needed to successfully implement technology at higher levels of use in their instruction? These questions could direct future research on how to better prepare prospective teachers.

A final aspect pertaining to the theoretical framework emerged through a trend that was observed during the analysis of the third research question. It was observed during six of the seven class sessions that teachers who used technology at the levels of redefinition and modification also used an instructional model in which students were able to explore concepts in a self-directed way using technology. It was also noted that this was most prevalent with teachers who scored higher in TPACK and self-efficacy and in situations with higher levels of student knowledge demonstrated through SCK, STK, and STCK. Therefore, it would be logical to examine the implications of this combined framework model on lesson design and implementation. Furthermore, it would be interesting to study the relationship between self-efficacy of the teacher and student independence in technology-rich lessons. Was this an isolated occurrence, or is there an observable correlation between TPACK, self-efficacy, and lesson design resulting in higher student achievement?

Closing Thoughts

In this study, I sought to understand the potential impact that focused PD sessions could have on improving technology implementation in secondary mathematics instruction at High School X. The study was based on a foundation of a holistic, combined theoretical framework that equally valued knowledge types and self-efficacy. Two PD sessions designed to meet focused needs were implemented. The results of the study confirmed findings in the existing literature. The PD sessions had a positive impact on the knowledge, level of technology use, and self-efficacy of teachers. This positive impact was corroborated through observations of instruction. On the whole, focused PD sessions have the potential to improve how teachers use technology for teaching and learning in secondary mathematics instruction.

A few decades ago, technology was a separate component of teaching and learning—more or less an accessory. As time progressed and new technological advances were achieved, the potential of technology to transform learning grew. The COVID-19 pandemic cemented this paradigm shift. It is now inescapable! To be successful in facilitating learning, teachers must robustly understand how best to use technology. Twenty-first-century learning requires 21st-century methods and tools. I trust this study can assist in providing a path forward to solidify the excellent work that amazing teachers do every day by affording them the tools and knowledge to be successful and confident in their practice.

REFERENCES

Abbitt, J. T. (2011). An investigation of the relationship between self-efficacy beliefs about technology integration and technological pedagogical content knowledge (TPACK) among preservice teachers. *Journal of Digital Learning in Teacher Education*, *27*(4), 134–143.

Akyuz, D. (2018). Measuring technological pedagogical content knowledge (TPACK) through performance assessment. *Computers & Education*, *125*, 212–225.

Alabdulaziz, M. S. (2021). COVID-19 and the use of digital technology in mathematics education. *Education and Information Technologies*, *26*(6), 7609–7633.

Alabdulaziz, M. S., Aldossary, S. M., Alyahya, S. A., & Althubiti, H. M. (2021). The effectiveness of the GeoGebra programme in the development of academic achievement and survival of the learning impact of the mathematics among secondary stage students. *Education and Information Technologies*, *26*(3), 2685–2713.

Albano, G., Coppola, C., Iacono, U. D., Fiorentino, G., Pierri, A., & Polo, M. (2020). Technology to enable new paradigms of teaching/learning in mathematics: The digital interactive storytelling case. *Journal of E-learning and Knowledge Society*, *16*(1), 65–71.

Alrwaished, N., Alkandari, A., & Alhashem, F. (2020). Exploring in- and pre-service science and mathematics teachers’ technology, pedagogy, and content knowledge (TPACK): What next? *Teknologia Kemian Opetuksessa*, *1*(1), 6113–6131.

Aminah, N., & Wahyuni, I. (2019). The ability of pedagogic content knowledge (PCK) of mathematics teacher candidate based on multiple intelligent. *Journal of Physics: Conference Series, 1280*(4), 1-6.

Archambault, L., & Crippen, K. (2009). Examining TPACK among K-12 online distance educators in the United States. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 71–88.

Avci, Z. Y., O'Dwyer, L. M., & Lawson, J. (2020). Designing effective professional development for technology integration in schools. *Journal of Computer Assisted Learning*, *36*(2), 160–177.

Bakar, N. S. A., Maat, S. M., & Rosli, R. (2020). Mathematics teacher's self-efficacy of technology integration and technological pedagogical content knowledge. *Journal on Mathematics Education, 11*(2), 259–276.

Bates, C. C., & Morgan, D. N. (2018). Seven elements of effective professional development. *The Reading Teacher, 71*(5), 623–626.

Beatty, I. D., Gerace, W. J., Leonard, W. J., & Dufresne, R. J. (2006). Designing effective questions for classroom response system teaching. *American Journal of Physics*, *74*(1), 31–39.

Berlin, D. F., & White, A. L. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science and Mathematics, 112*(1), 20–30.

Bhattacharya, K. (2017). *Fundamentals of qualitative research: A practical guide*. Routledge.

Bowman, M. A., Vongkulluksn, V. W., Jiang, Z., & Xie, K. (2020). Teachers' exposure to professional development and the quality of their instructional technology use: The mediating role of teachers' value and ability beliefs. *Journal of Research on Technology in Education, 54*(2), 188–204.

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research: A systematic review of recent trends. *Computers & Education*, *114*, 255–273.

Bybee, R. W. (1997). The Sputnik era: Why is this educational reform different from all other reforms? *Reflecting on Sputnik Symposium: Linking the Past, Present, and Future of Educational Reform.* National Academy of Sciences.

Carroll, L. S. L. (2017). A comprehensive definition of technology from an ethological perspective. *Social Sciences*, *6*(4), 126-146.

Chick, H., & Beswick, K. (2018). Teaching teachers to teach Boris: A framework for mathematics teacher educator pedagogical content knowledge. *Journal of Mathematics Teacher Education, 21*(5), 475-499.

Chuttur, M. Y. (2009). Overview of the technology acceptance Model: Origins, developments and future directions. *Working Papers on Information Systems, 9*(37), 1–23.

Clark, V. L. P., & Ivankova, N. V. (2015). *Mixed methods research: A guide to the field* (vol. 3). SAGE.

Clark-Wilson, A., & Hoyles, C. (2018). A research-informed web-based professional development toolkit to support technology-enhanced mathematics teaching at scale. *Educational Studies in Mathematics, 102*(3), 343–359.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. SAGE.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (with Espinoza, D.). (2017). *Effective teacher professional development*. Learning Policy Institute. Retrieved from https://learningpolicyinstitute.org/sites/default/files/product-files/Effective_Teacher_Professional_Development_REPORT.pdf

Davis, F. D. (1985). *A technology acceptance model for empirically testing new end-user information systems: Theory and results* [Doctoral dissertation, Massachusetts Institute of Technology]. ProQuest Dissertations and Theses Global.

Dawson, F. (2010). Standards movement. In T. C. Hunt (Ed.), *Encyclopedia of Educational Reform and Dissent* (pp. 855–858). SAGE.

Demana, F., & Waits, B. (1987). Problem solving using microcomputers. *College Mathematics Journal, 18*(3), 236–241.

Depaepe, F., Torbeyns, J., Vermeersch, N., Janssens, D., Janssen, R., Kelchtermans, G., Verschaffel, L., & Van Dooren, W. (2015). Teachers' content and pedagogical content knowledge on rational numbers: A comparison of prospective elementary and lower secondary school teachers. *Teaching and Teacher Education, 47*, 82-92.

Driskell, S. O., Bush, S. B., Ronau, R. N., Niess, M. L., Rakes, C. R., & Pugalee, D. K. (2018). Mathematics education technology professional development: Changes over several decades. In M. Khosrow-Pour (Ed.) *Teacher training and professional development: Concepts, methodologies, tools, and applications* (pp. 115–144). IGI Global.

Dufresne, R. J., Gerace, W. J., Leonard, W. J., Mestre, J. P., & Wenk, L. (1996). Classtalk: A classroom communication system for active learning. *Journal of Computing in Higher Education*, *7*(2), 3–47.

Ganesan, N., & Eu, L. K. (2020). The effect of dynamic geometry software Geometer's Sketchpad on students' achievement in topic circle among form two students. *Malaysian Online Journal of Educational Technology, 8*(2), 58–68.

Georgiou, Y., & Ioannou, A. (2021). Developing, enacting and evaluating a learning experience design for technology-enhanced embodied learning in math classrooms. *TechTrends: Linking Research & Practice to Improve Learning*, *65*(1), 38–50.

Gomez, D.M., & Videla, M.V. (2021). Prospective primary school teachers' and secondary school math teachers' mathematics knowledge and beliefs. In K. Kaen (Ed.) *Proceedings of the 44th conference of the international group for the psychology of mathematics education*. 329-336.

Gómez-Blancarte, A. L., & Miranda, I. (2021). Participation and reification: Two basic design principles for mathematics professional development programs. *Canadian Journal of Science, Mathematics and Technology Education*, *21*(3), 625-638.

Graham, R. C., Burgoyne, N., Cantrell, P., Smith, L., St Clair, L., & Harris, R. (2009). Measuring the TPACK confidence of inservice science teachers. *TechTrends*, *53*(5), 70–79.

Harmes, J. C., Welsh, J. L., & Winkelman, R. J. (2016). A framework for defining and evaluating technology integration in the instruction of real-world skills. In Y. Rosen, S. Ferrara, & M. Mosharraf (Eds.), *Handbook of research on technology tools for real-world skill development* (pp. 137–162). IGI Global.

Hegedus, S., Laborde, C., Brady, C., Dalton, S., Siller, H-St, Tabach, M., Trgalova, J., & Moreno-Armella, L. (2017). *Uses of technology in upper secondary mathematics education*. Springer.

Hoffman, W. (1965). Computers for school mathematics. *Mathematics Teacher, 58*, 393–401.

Honey, S. (2018). Graphics calculators in the primary classroom: Student-teachers' beliefs and the TPACK framework. *International Journal for Technology in Mathematics Education, 25*(3), 3–16.

Horton, E. M. (1937). Calculating machines and the mathematics teacher. *The Mathematics Teacher, 30*(6), 271–276. http://www.jstor.org/stable/27952073

Hsu, C. Y., Tsai, M. J., Chang, Y. H., & Liang, J. C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Journal of Educational Technology & Society*, *20*(1), 134–143.

Hughes, J., Thomas, R., & Scharber, C. (2006). Assessing technology integration: The RAT—replacement, amplification, and transformation—framework. In *Proceedings of SITE 2006: Society for Information Technology and Teacher Education International Conference* (pp. 1616–1620). Association for the Advancement of Computing in Education.

Humes, V. (2017). *The impact of TPACK, SAMR, and teacher effectiveness on student academic growth in eighth grade language art and mathematics*. [Doctoral dissertation, Youngstown State University]. ProQuest Dissertations and Theses Global.

Ivankova, N. V. (2014). *Mixed methods applications in action research*. Sage.

Jiang, Z., White, A., Sorto, A., & Rosenwasser, A. (2013). Investigating the impact of a technology-centered teacher professional department program. In *Proceedings of the 11th International Conference on Technology in Mathematics Teaching* (pp. 156–161).

Kandemir, M. A., & Demirbag-Keskin, P. (2019). Effect of graphing calculator program supported problem solving instruction on mathematical achievement and attitude. *International Journal of Research in Education and Science, 5*(1), 203-223.

Karadeniz, I., & Thompson, D. R. (2018). Precalculus teachers' perspectives on using graphing calculators: an example from one curriculum. *International Journal of Mathematical Education in Science and Technology, 49*(1), 1-14.

Karakus, F., & Aydin, B. (2017). The effects of computer algebra system on undergraduate students' spatial visualization skills in a calculus course. *Malaysian Online Journal of Educational Technology, 5*(3), 54–69.

Karp, S. (2014). The problems with the Common Core. *Rethinking Schools*, 28(2). http://www.rethinkingschools.org/archive/28_02/28_02 _karp.shtml.

Kaya, S., & Dag, F. (2013). Turkish adaptation of technological pedagogical content knowledge survey for elementary teachers. *Educational Sciences: Theory and Practice, 13*(1), 302–306.

Kazu, I. Y., & Erten, P. (2014). Teachers' technological pedagogical content knowledge self-efficacies. *Journal of Education and Training Studies, 2*(2), 126–144.

Kilpatrick, W. H. (1934). Definition of the activity movement today. In G. M. Whipple (Ed.), *The thirty-third yearbook of the National Society for the Study of Education*, part 2: *The activity movement* (pp. 46–64). Public School Publishing Company.

Kim, C., Kim, M. K., Lee, C., Spector, J. M., & DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education, 29*, 76–85.

Kimmons, R., Graham, C. R., & West, R. E. (2020). The PICRAT model for technology integration in teacher preparation. *Contemporary Issues in Technology and Teacher Education*, *20*(1), 176–198.

Klein, D. (2003). A brief history of American K-12 mathematics education in the 20th century. In J. Royer (ed.) *Mathematical Cognition*, 175–259. Information Age.

Koh, J. H. L., & Chai, C. S. (2014). Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design. *Computers & Education*, *70*, 222–232.

Kohler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70.

Laumakis, P., & Herman, M. (2018). Comparing computer algebra systems in calculus I: TI-Nspire CAS versus TI-89. *International Journal for Technology in Mathematics Education*, *25*(4), 3–19.

Lee, M. H., & Tsai, C. C. (2010). Exploring teachers' perceived self-efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. *Instructional Science*, *38*(1), 1–21.

Liao, Y. C., Ottenbreit-Leftwich, A., Karlin, M., Glazewski, K., & Brush, T. (2017). Supporting change in teacher practice: Examining shifts of teachers' professional development preferences and needs for technology integration. *Contemporary Issues in Technology and Teacher Education*, *17*(4), 522–548.

Lo, C. K. (2021). Design principles for effective teacher professional development in integrated STEM education: A systematic review. *Educational Technology & Society*, *24*(4), 136–152.

Loss, C. (2010). Life adjustment education. In T. C. Hunt (Ed.), *Encyclopedia of educational reform and dissent* (pp. 525–527). SAGE.

Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N. & Hewson, P. W. (2010). *Designing professional development for teachers of science and mathematics* (3rd ed.). Corwin Press.

Lydon, S., & King, C. (2009). Can a single, short continuing professional development workshop cause change in the classroom? *Professional Development in Education, 35*(1), 63–82.

Lyublinskaya, I., & Tournaki, N. (2011). The effect of teaching and learning with Texas Instruments handheld devices on student achievement in algebra. *Journal of Computers in Mathematics & Science Teaching, 30*(1), 5–35.

Mao, Y., White, T., Sadler, P. M., & Sonnert, G. (2017). The association of precollege use of calculators with student performance in college calculus. *Educational Studies in Mathematics, 94*(1), 69-83.

McFarland, J. W. (1954). What about life adjustment education? *High School Journal, 37*(8), 243–250.

Meriç, G. (2014). Determining science teacher candidates' self-reliance levels with regard to their technological pedagogical content knowledge. *Eğitimde Kuram ve Uygulama*, *10*(2), 352–367.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook*. SAGE.

Mohammad, A. M. (2019). Students' attitude towards computer algebra systems (CAS) and their choice of using CAS in problem-solving. *International Journal of Mathematical Education in Science and Technology, 50*(3), 344–353.

Moon, J., & Ke, F. (2020). In-game actions to promote game-based math learning engagement. *Journal of Educational Computing Research, 58*(4), 863–885.

Morais, A., Barragues, J. I., & Guisasola, J. (2015). Using a classroom response system for promoting interaction to teaching mathematics to large groups of undergraduate students. *Journal of Computers in Mathematics & Science Teaching, 34*(3), 249–271.

Mu'alimin, M. A. (2019). Application of classroom response systems (CRS): Study to measure student learning outcome. *International Journal of Emerging Technologies in Learning, 14*(14), 132–142.

Mulenga, E. M., & Marbán, J. M. (2020). Is COVID-19 the gateway for digital learning in mathematics education?. *Contemporary Educational Technology*, *12*(2), ep269.

National Council of Teachers of Mathematics. (1980). *An agenda for action: Recommendations for school mathematics of the 1980s.*

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.*

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.*

Niederhauser, D. S., & Perkmen, S. (2008). Validation of the intrapersonal technology integration scale: Assessing the influence of intrapersonal factors that influence technology integration. *Computers in the Schools*, *25*(1–2), 98–111.

Pittalis, M. (2021). Extending the Technology Acceptance Model to evaluate teachers' intention to use dynamic geometry software in geometry teaching. *International Journal of Mathematical Education in Science & Technology, 52*(9), 1385–1404.

Plass-Nielsen, J., & Wolter Nielsen, O. B. (2019). How to enhance interest in mathematics by using game-based learning. *Proceedings of the European Conference on Games Based Learning*, 1024–1027.

Puentedura, R. R. (2003). *A matrix model for designing and assessing network-enhanced courses. Hippasus.* Retrieved from http://www.hippasus.com/ resources/matrixmodel/

Puentedura, R. R. (2010). *SAMR and TPCK: Intro to advanced practice*. *Hippasus.* Retrieved from http://hippasus.com/resources/sweden2010/SAMR_TPCK_IntroToAdvanced Practice.pdf

Romberg, T. A. (2010). Introduction to the CD collection: Classic publications on the mathematics curriculum. In B. J. Reys, R. E. Reys, & R. Rubenstein (Eds.), *Mathematics curriculum: Issues, trends, and future directions* (pp. 1–21). National Council of Teachers of Mathematics.

Ronau, R. N., & Rakes, C. R. (2012). A comprehensive framework for teacher knowledge (CFTK): Complexity of individual aspects and their interactions. In *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches* (pp. 59–102). IGI Global.

Saltan, F., & Arslan, K. (2017). A comparison of in-service and pre-service teachers' technological pedagogical content knowledge self-confidence. *Cogent Education*, *4*(1), 1-12.

Schaughency, M. D. (1955). Teaching arithmetic with calculators. *The Arithmetic Teacher*, *2*(1), 21–22. http://www.jstor.org/stable/41183756

Scher, D. (1999). Lifting the curtain: The evolution of the Geometer's Sketchpad. *The Mathematics Educator*, *10*(2), 42-48.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK) the development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123–149.

Semiz, K., & Ince, M. L. (2012). Pre-service physical education teachers' technological pedagogical content knowledge, technology integration self-efficacy and instructional technology outcome expectations. *Australasian Journal of Educational Technology, 28*(7),1248-1265.

Şimşek, K., & İpek, J. (2019). Effects of computer algebra systems on academic success in blended learning environments. *Necatibey Faculty of Education Electronic Journal of Science & Mathematics Education*, *13*(2), 651–679.

Stein, M. K., & Smith, M. S. (2018). *Five practices for orchestrating productive mathematics discussions*. SAGE.

Stengle, B. S. (2010). Progressive education. In T. C. Hunt (Ed.), *Encyclopedia of educational reform and dissent* (pp. 735–742). SAGE.

Sztajn, P., Borko, H., & Smith, T. (2017). Research on mathematics professional development. In J. Cai (Ed.), *Compendium for research in mathematics education* (pp. 793–823). National Council of Teachers of Mathematics.

Texas Education Agency. (2021, November 2). *House Bill 3906*. Texas Education Agency. Retrieved from https://tea.texas.gov/student-assessment/assessment-initiatives/hb-3906

Thurm, D., & Barzel, B. (2020). Effects of a professional development program for teaching mathematics with technology on teachers' beliefs, self-efficacy and practices. *ZDM – Mathematics Education*, *52*(7), 1411–1422.

Tokac, U., Novak, E., & Thompson, C. G. (2019). Effects of game-based learning on students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning, 35*(3), 407–420.

Tsai, H. C. (2015). A senior teacher's implementation of technology integration. *International Education Studies, 8*(6), 151–161.

Urdan, T. C. (2017). *Statistics in plain English*. Taylor & Francis.

Venkatesh, V., & Davis, F. D. (1996). A model of the antecedents of perceived ease of use: Development and test. *Decision Sciences, 27*(3), 451–481.

Verschaffel, L., Depaepe, F., & Mevarech, Z. (2019). Learning mathematics in metacognitively oriented ICT-based learning environments: A systematic review of the literature. *Education Research International*. *2019*. https://doi.org/10.1155/2019/3402035.

Watson, G. (2006). Technology professional development: Long-term effects on teacher self-efficacy. *Journal of Technology and Teacher Education*, *14*(1), 151–166.

Wijaya, T. T., Rizki, L. M., Yunita, W., Salamah, U., Pereira, J., Zhang, C., Xinxin, L. & Purnama, A. (2021). Technology integration to teaching mathematics in higher education during coronavirus pandemic using SAMR model. *Journal of Physics: Conference Series*, *2123*(1). https:doi.org/10.1088/1742-6596/2123/1/012043

Young, J. R., Young, J. L., & Hamilton, C. (2013). The use of confidence intervals as a meta-analytic lens to summarize the effects of teacher education technology courses on preservice teacher TPACK. *Journal of Research on Technology in Education*, *46*(2), 149–172.

Zhan, Y., Quan, J., & Ren, Y. (2013). An empirical study on the technological pedagogical content knowledge development of pre-service mathematics teachers in

China. *International Journal of Social Media and Interactive Learning Environments*, *1*(2), 199–212.

APPENDIX A IRB DETERMINATION LETTER

TEXAS A&M UNIVERSITY

DIVISION OF RESEARCH

NOT HUMAN RESEARCH DETERMINATION

February 03, 2022

Type of Review: Initial Review Submission Form
Title: IMPROVING THE IMPLEMENTATION OF TECHNOLOGY AND TPACK AND TEACHER SELF-EFFICACY WITHIN SECONDARY MATHEMATICS INSTRUCTION THROUGH TARGETED PROFESSIONAL DEVELOPMENT
Investigator: Radhika Viruru
IRB ID: IRB2022-0146
Reference Number: 137652
Funding:

Dear Radhika Viruru:

The Institution determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations.

Further IRB review and approval by this organization is not required because this is not human research. This determination applies only to the activities described in this IRB submission and does not apply should any changes be made. If changes are made you must immediately contact the IRB about whether these activities are research involving humans in which the organization is engaged. You will also be required to submit a new request to the IRB for a determination.

Please be aware that receiving a 'Not Human Research Determination' is not the same as IRB review and approval of the activity. IRB consent forms or templates for the activities described in the determination are not to be used and references to TAMU IRB approval must be removed from study documents.

If you have any questions, please contact the IRB Administrative Office at 1-979-458-4067, toll free at 1-855-795-8636.

Sincerely,
IRB Administration

APPENDIX B PRETEST AND POSTTEST

Each answer is to be given on a scale from 1 (lowest) to 5 (highest).

1. I know how to create a basic presentation using PowerPoint Nearpod or a similar program.
2. I know how to create a document with text, graphics, and mathematical notation in a word processing program.
3. I know how to create and edit a website on Google Sites or the district website.
4. I know how to use the TI-Nspire calculator for the content I teach.
5. I know how to use the TI-Nspire teacher software for the content I teach.
6. I have the technical skills I need to use technology and troubleshoot issues.
7. I have had sufficient trainings on how to work with the different technologies in my classroom.
8. I know how to use technological representations (i.e., multimedia, visual demonstrations, etc.) to demonstrate specific concepts in my content area.
9. I know how to use various courseware programs to deliver instruction and facilitate lessons (e.g., Google Classroom, iXL, etc).
10. I know how to use digital technologies to create, analyze, and manipulate mathematical models.
11. I know how to use digital technologies to record, organize, and analyze data that would otherwise be difficult to gather, assess, and see.
12. I can tell whether the digital activities represent the targeted subject-matter knowledge.
13. I know about technologies that I can use for understanding and doing mathematics.
14. I know how to implement different methods of teaching with technology.

15. I know how to use digital technologies to improve communication with and between students.
16. I know how to effectively manage a technology-rich classroom.
17. I know how to use digital technologies to actively engage students in learning.
18. I know how to use digital technologies to help in assessing student learning.
19. I know the relevant instructional strategies of digital activities.
20. I know how to integrate digital activities into teaching.
21. I can adapt the use of the technologies that I am learning about to different teaching activities.
22. I know how to use technology to predict students' skill/understanding of a particular topic.
23. I know how to use technologies to facilitate higher-level critical thinking about mathematics in the classroom.
24. I know how to use technologies that facilitate topic-specific mathematics activities in the classroom.
25. I know how to use technologies to facilitate and invoke student communication and collaboration.
26. I know how to teach lessons that appropriately combine my teaching subject, digital activities, and teaching approaches.
27. I know how to craft real-world problems about the content knowledge and represent them through digital activities to engage my students.
28. I know how to create self-directed learning activities and lessons for students using technology tools.

29. I know how to teach lessons that appropriately combine mathematics, technologies, and teaching approaches.
30. I know how to select technologies to use in my classroom that enhance what I teach, how I teach, and what students learn.
31. I know how to provide leadership in helping others to coordinate the use of content, technologies, and teaching approaches at my school and/or district
32. I know how to choose technologies that enhance the content for a lesson.
33. I consistently use technology to transform learning by redesigning existing learning tasks in a way that they would be impossible to be completed without technology.
34. I consistently use technology to transform learning by creating new tasks that would be impossible without technology.
35. I feel confident that I can teach relevant subject matter with appropriate use of instructional technology.
36. I feel confident that I can select appropriate instructional technology for instruction based on standards–based pedagogy.
37. I feel confident that I can regularly incorporate appropriate instructional technologies into my lessons to enhance student learning.
38. I feel confident that I can help students when they have difficulty with instructional technology.
39. I feel confident that I have the necessary skills to use instructional technology for instruction.

40. I feel confident that I can effectively use instructional technology in my teaching.[1]

For Pretest Only…Yes or No Answer Choices

41. I am willing to be observed while teaching a technology-rich lesson during the first nine-week grading period.

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[1] These 40 questions can be divided into six categories: TK (questions 1 to 7; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Koh & Chai, 2014; Schmidt et al., 2009; Semiz & Ince, 2012), TCK (questions 8 to 15; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Koh & Chai, 2014; Schmidt et al., 2009), TPK (questions 16 to 21; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Koh & Chai, 2014; Schmidt et al., 2009), TPACK (questions 22 to 32; Archambault & Crippen, 2009; Graham et al., 2009; Hsu et al., 2017; Koh & Chai, 2014; Schmidt et al., 2009; Semiz & Ince, 2012), level of technology use (questions 33 and 34; Puentadura, 2007), and self-efficacy (questions 35 to 40; Hsu et al., 2017; Niederhauser & Perkmen, 2008; Semiz & Ince, 2012).

APPENDIX C OBSERVATION FORM & MANUAL

Knowledge				***Integration***				
Student: Actions/Conversations	CK	TK		Technology & Instructional Strategies (What)				
	TCK			T - Controlled S - Passive	T - Driven S - Considered	T - Led S - Centered	T - Integrated S - Driven	T - Facilitation S - Led
				Evidences (How)				
Teacher: Actions/Conversations/Design	CK	PCK	PK	Student		Teacher		
	TCK	TPACK	TPK	Substitution/ Replacement	Augmentation	Modification	Redefinition/ Transformation	
	TK							

Classroom Technology Observation Form

Observer's Training Manual

CLASSROOM TECHNOLOGY OBSERVATION FORM

This manual contains operational definitions for the constructs and categories the classroom observation instrument. One copy of the observation form should be completed during a classroom observation.

The Classroom Observation Form is divided into two main columns. The left column focuses on how knowledge types are demonstrated. The right column focuses on how technology is integrated into classroom teaching and learning. Each column contains specific subheadings related to the column focus. In the left column the major subheadings focus on what is demonstrated by students and teachers. These are then divided into the specific knowledge types demonstrated by either teachers or students. In the right column the major subheadings focus on recording the evidence of demonstration, level of student-centeredness, and level of technology task. The level of technology task contains four areas to record evidence of each level of technology task demonstrated. Detailed descriptions are described below:

- **Knowledge:** Student Actions/Conversations

The construct "Knowledge Student Actions/Conversations" describes the types of knowledge demonstrated by the students as they interact with the teacher and as a result of the teacher's impact. Observed examples of each knowledge should be recorded. Three types of knowledge are operationalized as follows:

1. **Content Knowledge (CK)** – This category signifies what students demonstrate about knowledge specific to the content. This knowledge is specific to the lesson

and should be aligned with primary and supporting standards. This is often demonstrated based on the interactions students have with each other and with the teacher. Responses to teacher questions and prompts are often primary inputs for this category. An example of this could be understanding linear functions.

2. **Technological Knowledge (TK)** – This category signifies what students demonstrate about knowledge specific to technology. This knowledge is specific to technologies students interact with aligned to the current lesson. Content is not a part of this category. This is simply what students show they know about technology usage. Responses to teacher questions and prompts are often primary inputs for this category. An example of this could include understanding the functions and processes of a calculator
3. **Technological Content Knowledge (TCK)** – This category signifies what students demonstrate about knowledge specific to conquering content with technology. This knowledge is specific to the convergence of content and technology demonstrated simultaneously. Responses to other students and teacher questions and prompts are often primary inputs for this category. An example of this could include graphing and analyzing linear functions using a graphing utility or calculator.

- **Knowledge:** Teacher Actions/Conversations

The construct "Knowledge Teacher Actions/Conversations" describes the types of knowledges demonstrated by the teachers as they interact with the students and facilitate learning. These can be demonstrated implicitly and explicitly. Observed examples of each knowledge should be recorded. Seven types of knowledge are operationalized as follows:

1. **Content Knowledge (CK)** – This category signifies what teachers demonstrate about knowledge specific to the content. This knowledge is specific to the lesson and should be aligned with primary and supporting standards. This may be demonstrated through both facilitation and lecture.

2. **Pedagogical Knowledge (PK)** – This category signifies what teachers demonstrate about knowledge specific to how to teach. This does not include technology or content. Examples of this could include general instructional strategies.

3. **Technological Knowledge (TK)** – This category signifies what teachers demonstrate about knowledge specific to technology. This knowledge is specific to technologies teachers interact with aligned to the current lesson. Content is not a part of this category. This is simply what teachers show they know about technology usage. An example of this could include understanding the functions and processes of a calculator or lesson facilitation software.

4. **Pedagogical Content Knowledge (PCK)** – This category signifies what knowledge teachers demonstrate about how to teach their specific content. This knowledge is specific to methods and strategies for teaching discipline-specific content. An example of this could include understanding the how to teach factoring using multiple methods within a Concrete-Representational-Abstract construct.

5. **Technological Content Knowledge (TCK)** – This category signifies what knowledge teachers demonstrate about the intersection of their content with technology. This does not address how teaching is executed pedagogically. This would include both basic tasks and deeper level analysis with technology. An

example of this could include understanding the use of graphing utilities in analyzing functions.

6. **Technological Pedagogical Knowledge (TPK)** – This category signifies what knowledge teachers demonstrate about how to teach with technology. This is not specific to any individual content domain. This focuses on teacher knowledge of teaching as a whole with technology. This also includes demonstrations of strategies for classroom management that are specific to technology enriched teaching and learning. An example of this could include understanding how to use communication technologies to facilitate collaboration between students in learning tasks.

7. **Technological Pedagogical and Content Knowledge (TPACK)** – This category signifies what knowledge teachers demonstrate about how to teach and facilitate the learning of their specific content with technology. This requires the simultaneous demonstration of CK, PK, and TK. This domain encompasses what teachers know about how to teach their specific content using technology and instructional strategies that are specific to technology. An example of this could include understanding how to teach modeling with trigonometric functions using virtual graphing platforms.

- **Integration:** Technology & Instructional Strategies (What)

The construct “Technology & Instructional Strategies (What)” describes the evidence of what strategies for instruction and technology use are present. Evidence could include any type of instructional strategy present. Descriptions of how each technology is used should be recorded in this section by the observer. This section will likely have overlap with the teacher knowledge quadrant and may have overlap with the subsequent integration constructs.

• **Integration:** Teacher-Student Scale

The construct "Teacher-Student Scale" describes level of control, focus, and leadership of the lesson for teachers and students. Only one level should be circled. The observer should choose the highest level observed during the lesson. If a higher level is only briefly demonstrated in the lesson, then the observer may box or star the most dominant level in order to fairly capture the nuances of the lesson. Five levels are operationalized as follows:

1. **Level 1: Teacher Controlled…Student Passive** – This level signifies classroom learning in which the teacher has total control and action in the lesson. The students are passive recipients of learning. Technology usage is primarily demonstrated in teacher modeling. Students may passively receive content through technology.
2. **Level 2: Teacher Driven…Student Considered** – This level signifies classroom learning in which the teacher has most of the control and action in the lesson. It is evident that students are considered based on how the lesson is design and delivered. Technology usage is primarily demonstrated in teacher modeling with student mimicking.
3. **Level 3: Teacher Led…Student Centered** – This level signifies classroom learning in which the teacher and students have equal control of the learning process. Some student choice may be present. Technology usage is primarily demonstrated in equal teacher and student use. Note: This level may also be connected with higher levels of technology tasks as determined by the "Technology Task Level Scale".

4. **Level 4: Teacher Integrated…Student Driven** – This level signifies classroom learning in which the teacher directs the lesson from a more passive perspective. Student choice will likely be present. The students drive learning and are clearly focused on through differentiation and planning. Technology usage is demonstrated through student usage while the teacher assists in both a hands-on and hands-off manner. Note: This level will likely be connected with higher levels of technology tasks as determined by the "Technology Task Level Scale".
5. **Level 5: Teacher Facilitated…Student Led** – This level signifies classroom learning in which the teacher has only a facilitation role in the lesson. The students actively lead the lesson and drive learning. Students are often involved in creation with technology. Technology usage is demonstrated through student usage while the teacher assists without assuming any control of technology use. Note: This level must be connected with higher levels of technology tasks as determined by the "Technology Task Level Scale".

- **Integration:** Evidences (How)

The construct "Evidences (How)" describes examples of what is done in the lesson by the two types of participants. Observations of actions of learning and teaching should be recorded by the observer. This section will have overlap with other sections in both columns. Two types of evidence are operationalized as follows:

1. **Students** – The evidence of what students do in the lesson should be recorded. Actions and conversations are relevant. This should naturally overlap with the student knowledge quadrant.

2. **Teacher** – The evidence of what teachers do in the lesson should be recorded. Actions and conversations are relevant. This should naturally overlap with the teacher knowledge quadrant.

- **Integration:** Technology Task Level Scale

The construct "Technology Task Level Scale" describes the level of technology tasks present in the lesson. This measures and describes the quality and level of technology use and what can be obtained through the use of technology in the lesson. Multiple levels will likely be present in each lesson. The observer should record examples of evidence for each level and circle the highest level observed. Four levels of technology tasks are operationalized as follows:

1. **Substitution/Replacement** – This level signifies the lowest level of technology use. Technology is used in a way that substitutes for nontechnology tasks but with no improvement in function or efficiency.
2. **Augmentation** – This level signifies the second lowest level of technology use. Technology is used in a way that substitutes for nontechnology tasks but with improvement in function or efficiency.
3. **Modification** – This level signifies the highest level of technology use. Technology is used in a way that significantly modifies the design and implementation of learning tasks. The beginning of transformation can be seen in the lesson. Technology allows for tasks to take place that would be otherwise difficult without the use of technology.

4. **Redefinition/Transformation** – This level signifies the highest level of technology use. Technology is used in a way that redefines what is possible by offering choices for instruction and learning that would otherwise be impossible without the use of technology.