INTERACTIVE WHITEBOARDS: A TEACHER'S TOOL FOR ELICITING STUDENT THINKING IN THE SECONDARY MATHEMATICS CLASSROOM

by

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(Under the Direction of Denise A. Spangler)

ABSTRACT

I examined how 8 experienced secondary mathematics teachers used interactive whiteboards (IWBs) to elicit student thinking. The study design used a two-phase process: (1) prequalification of participants based on experiences levels involving IWBs and student-centered instruction and (2) multiple data collection cycles of observations followed by video-stimulated recall interviews. Classroom observations involved whole-class discussion in which teachers engaged students in an exploration of mathematics that attended to problem solving, multiple representations, and connections.

I analyzed the data using two frameworks that allowed me to examine teaching practices specific to mathematics instruction. The first framework, emergent perspective (Cobb & Yackel, 1996), promotes teaching mathematics as a sociocultural process. The second framework, Technological Pedagogical and Content Knowledge (TPACK, Mishra & Koehler, 2006), delineates the combinations of teacher knowledge domains (technological, pedagogical, and mathematics content) that are enacted in technologically rich environments.

I developed a classification scheme for the way teachers used IWBs to support their instruction: (a) digital accentuation, (b) digital proximity, and (c) digitally enabled exploration. When using the IWB for digital accentuation the teachers used colored pens and highlighters to draw attention to particular features of graphs, equations, or diagrams. Digital proximity consisted of two processes–bringing or keeping elements on the screen together and deliberately separating elements on the screen. Teachers used the IWB features of extending pages or shrinking existing material to create space for new material or to keep related content in close proximity. They created new pages, hid content behind covers, and used the undo feature to visually separate content that they saw as unrelated or not germane to the task at hand. Students rarely used these IWB features. Teachers used a variety of IWB features to experiment with mathematical ideas. Although the suggestions for experimentation came from students, the teacher was generally in control of the IWB. Teachers' use of the IWB classified as digitally enabled exploration reflects the coincidence of all three TPACK domains. I propose that if a teacher's instructional goal is to enact IWB-based lessons involving student-centered problem solving, that instruction needs to reflect the concurrence of all three TPACK knowledge domains.

INDEX WORDS: interactive whiteboards, mathematics education, technological pedagogical and content knowledge, video-stimulated recall

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DEDICATION

To my mother, Yvonne Salmoni, who has been there for me from day one. Thank you for all the love, support, encouragement, and patience you selflessly poured into my days and nights in pursuit of this doctoral degree.

To my daughters, Julia and Alexandria Marshall, who generously shared their mother with my career aspirations of becoming a research scholar, I thank you for your love, support, and encouragement to forge ahead in pursuit of this doctoral degree. I look forward to providing the same love, support, and encouragement to the both of you in your future academic journeys. As I have said in numerous text messages: "I love you more!!!"

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CHAPTER 1

INTRODUCTION

I introduce this research study of teachers' use of interactive white boards with concern and hope, similar to Heid's (1997) views expressed over a decade ago yet remaining relevant to our technologically evolving field of mathematics education:

> What is intended to be exciting and innovative may lose its excitement as it is incorporated as a curriculum routine. . . . Keeping students' sights on the "big ideas" of mathematics instead of on the glamour of the technological tools will become increasingly important and difficult in technologically rich mathematics classrooms that may have drawn students' attention precisely because of the intrigue of those tools. (p. 12)

The National Council of Teachers of Mathematics (NCTM, 2000) has recognized the value of technology as "an essential component of the [mathematics classroom] environment" (p. 3) and as an important component of a rigorous mathematics education. A great deal of resources in the form of time, money, and professional capital has influenced the design and the deployment of educational technology. This technology can enhance the learning environment by offering students a means to "focus on decision making, reflection, reasoning, and problem solving" (NCTM, 2000, p. 24). In turn, teachers can leverage these enhancements by making use of their pedagogical benefits to lead to increased student understanding of mathematical concepts.

As a former secondary teacher of mathematics with a prior career in new technology development, I became interested in how digital technology enhanced my classroom's learning environment. I was not interested in how educational technology offered ways for teachers to present mathematical content using high quality graphics or multimedia presentations that might rival the video games ever present in my students' personal lives for the sole purpose of captivating attention. Rather I sought to understand how teachers might engage their students in exploring mathematics in a manner that was interactive and dynamic. I envisioned this learning environment as a classroom where teachers and students shared ideas that were creative and spontaneous. I propose that teachers are in a position to extend the pedagogical benefits that educational technology affords for eliciting student thinking when teachers and students interact with the many features and functionalities of interactive whiteboards (IWBs).

Background

Interactive whiteboard technology is a fairly recent innovation. David Martin and Nancy Knowlton first described the product idea in 1986 while driving through upstate New York (SMART Technologies, 2013). In 1991, SMART Technologies produced the first IWB as an innovative device designed to support collaborative discussion. By 2007, the British Educational Communication and Technology Agency (Becta) reported a marked increase across 258 secondary schools claiming the mean number of IWBs per school to be: 3.5, 18.0, and 22.3 for the years 2002, 2005, and 2007, respectively (Kitchen, Finch, & Sinclair, 2007). The research community commensurately followed this trend with scholarship exploring IWB usage across a variety of subject and geographical settings that include Australia, the United Kingdom, and the United States.

An interactive whiteboard is more than just a wall-mounted, touch-sensitive board. The typical equipment configuration includes a ceiling mounted digital projector with speakers, an interface for a laptop, vendor specific application software, and Internet access. Given this concentration of digital technology, some researchers refer to the IWB as a digital hub (Betcher

& Lee, p. 12). This idea of a digital hub is relevant to differentiating the pedagogical value of an IWB from other digital equipment that is not integrated.

When eliciting student thinking, teachers must balance effective classroom management with instructional strategies that support whole-class engagement in problem-solving discussions (Fraivillig, Murphy, & Fuson, 1999). Fraivillig and colleagues stressed, “Clearly, *eliciting* [emphasis added] and then using student descriptions of mathematical thinking is a complex and time-consuming task requiring patience, skill, and high levels of knowledge about individual children and about typical solution methods in major mathematical areas” (p. 167).

Students can share their exploration of mathematical concepts in a variety of forms. The National Governors Association Center for Best Practices and Council of Chief State School Officers (NGACBP & CCSSO) established the Common Core State Standards for mathematics proficiency promoting student competence in working with a variety of mathematical representations that include tables of numerical values, algebraic symbols, graphs, and diagrams (NGACBP & CCSO, 2012). Similarly, NCTM (2002) extends the importance of these multiple representations by emphasizing the need for secondary students to “develop an increased capacity to link mathematical ideas and a deeper understanding of how more than one approach to the same problem can lead to equivalent results” (p. 354). Teachers can make more effective use of digital instructional tools when they have an understanding of how to use various IWB features and functionalities to foster student thinking that explores these multiple and connected representations.

Rationale

Research literature involving the classroom use of technology has frequently reported outcomes with no descriptions of classroom events detailing teachers’ actions and roles (Zbiek &

Hollebrands, 2008). Zbiek and Hollebrands expanded upon their claim stating, "There may be indications of the curriculum used, the technology employed, and tests or other instruments involved. However, data collection limitations and preferences of most journals and proceedings preclude inclusion of the details of the *teaching* [emphasis added]" (p. 308). In light of this void in research reporting, Peressini and Knuth (2005) explained that in order to move toward NCTM's reformed vision of a mathematics classroom, "teachers will need to develop, practice, and implement new forms of instruction and assessment that are grounded in the meaningful use of technology" (p. 277). Consistent with this call for more specificity, Fey, Hollenbeck, and Wray (2010) called attention to this void by explaining the "appropriate use of . . . instructional tools and appropriate revision of curriculum priorities to reflect the changes in how mathematical work is done in a technology-rich environment, will require extensive and thoughtful study and experimentation" (p. 48). By detailing the ways eight teachers shared the IWB with their students, the present study addressed the research void of how teachers actually use IWBs as an instructional tool.

It is conceivable that the more multimodal the instructional experience, the more likely students will also express their thoughts, ideas, and questions using multidimensional forms of communication. For example, a student might prefer sharing a problem solution by demonstrating a mathematical property through the use of a visual feature on an interactive whiteboard as opposed to verbalizing his or her thoughts in front of the class. Moreover, it is possible that some students may find this form of visual communication more consistent with their own reasoning about the mathematics. The result is a dialogic space that has now expanded beyond verbal and written formats to include graphical animation. Franke et al. (2007) described the nature of this communication clarifying

> Not just any kind of student talk is expected to be productive for supporting or challenging students' thinking. Beyond providing answers, students must describe *how* they would solve problems and *why* they propose certain strategies and approaches. That is, for truly productive dialogue to occur, students must provide evidence of . . . the extent of their procedural knowledge. (p. 3)

With the availability of an IWB, teachers can encourage students to communicate their mathematical reasoning in ways other than the traditional approaches of handwritten homework assignments, oral responses to teacher questions, and problem solutions transcribed from paper to the classroom whiteboard.

The aim of this research study was to explore how teachers use interactive whiteboards as pedagogical tools to elicit student thinking in the secondary mathematics classroom. It is not enough to use technology; the challenge is identifying how teachers can choose to use it interactively in support of their lesson plan objectives. This challenge was stated similarly by Fey et al. (2010):

> Many mathematics classrooms already present students with an impressive array of technological tools for doing and learning mathematics. But access to tools is the easy part of transforming mathematics education. Figuring out how to use the tools effectively and appropriately is a far greater challenge. (p. 42)

The adoption of "digital technology has dramatically changed [the] routines and practices" (Mishra & Kohler, 2006, p. 1017) of many teachers' daily work responsibilities. In an effort to enhance teaching and learning, school systems are routinely installing IWBs in classrooms throughout the United States, United Kingdom, and Australia. With such a ubiquitous resource, we need to heed the warnings of Glover and Miller (2001): "If [an IWB] is only being used as an adjunct to teaching, [then] its potential remains unrealized and pedagogic change may not occur" (p. 258).

For this reason, I believe there is value in studying *how* teachers use interactive IWBs as a pedagogical tool. I explored the various ways secondary mathematics teachers integrated the use of this digital equipment into their lessons as a means of enhancing student-centered instruction. Given the finite resources and escalating pressure to enhance mathematical learning in the United States, it is essential that teachers make effective choices about which equipment to use and how best to incorporate it into their instruction.

Pedagogical decisions. I propose that effective use of educational technology requires that teachers make pedagogical decisions about how to use the technology informed by student thinking. Mishra and Koehler (2006) reinforced this message: “Quality teaching requires developing a nuanced understanding of the complex relationships between technology, content, and pedagogy, and using this understanding to develop appropriate, content-specific strategies and representations” (p. 1029). Unfortunately, teachers’ use of technology in the mathematics classroom does not always support student learning. Expressing similar concern, Mishra and Koehler (2006) stated, “Merely introducing technology to the educational process is not enough. The question of *what* teachers need to know in order to appropriately incorporate technology into their teaching has [only recently] received a great deal of attention” (p. 1018). Furthermore, they expressed a need for research to shift its focus from *what* teachers need to know and more toward *how* teachers can use the technology. If the way teachers incorporate technology into their classroom instruction is worthy of research inquiry, then the investigation of the ways teachers interpret student thinking when using educational technology is a next step to a more refined exploration of this phenomenon.

Pedagogical tool. Pea (1985) proposed that educators should view technology as a cognitive tool–one that extends the learner’s cognitive functioning through the process of constructing knowledge the student would not otherwise have been capable of understanding. Inconsistent with this perspective, many implementations of educational technology have focused on increasing teacher-student ratios. This type of focus is an example of Pea's claim that educational institutions are misdirecting their attention toward how they can enhance learning in the form of *amplification*, rather than *reorganization*. He considered this misguided use of technology (to increase the number of students affected by instruction) as one with no consideration for the type or quality of student learning. In further support of this perspective, Jonassen, Peck, and Wilson (1999) "argue that students cannot learn *from* teachers or technologies. Rather, students learn from *thinking*—thinking about what they are doing or what they did. . . . Thinking mediates learning; learning results from thinking" (p. 2). With an absence of research describing how and why teachers use IWBs, this study focused on exploring teachers' reasoning for the ways they used specific features in support of learning secondary mathematics concepts.

Researchers have aligned this conception of technological mediation with educational reform. For instance, Heid (2005) promoted the idea that technology mediates learning with the explanation that "learning is different in the presence of technology" (p. 348) as when students explore multiple representations of mathematics that are dependent on the dynamic relationships forged between the student and the technology. Similarly, Jonassen (1985) emphasized this relationship as being a partnership between user and technology. It is this sense of partnership that establishes the learning experience as one where technology serves as a cognitive tool. Hollenbeck, Wray, and Fey (2010) reinforced this conception of technology as a mediator by describing technology as a tool for promoting student exploration of mathematical ideas in addition to expanding the range of problem-solving opportunities.

Beauchamp (2006) claimed the features of interactive presentation tools have the potential to offer more participatory pedagogy through new forms of interactive teaching. My views on technology as a pedagogical tool are further informed by the research findings of Peressini and Knuth (2005). These researchers devised a classification framework describing how technology supports student learning. They defined five primary ways in which teachers use technology as a pedagogical tool in the mathematics classroom: (1) management tool, (2) communication tool, (3) evaluation tool, (4) motivational tool, and (5) cognitive tool. They drew attention to its use as a cognitive tool being especially important:

> From the perspective of school mathematics reform, [a cognitive tool enables teachers] to harness technology in ways that help students better understand mathematical algorithms, procedures, concepts, and problem-solving situations. In this capacity, as a *cognitive tool*, technology offers a unique means of supporting students' exploration of, and engagement with, mathematics. (p. 280)

Among the many ways teachers can use IWBs as an instructional tool, I focused this study on exploring the ways teachers use it as a cognitive tool for learning mathematics.

Research Questions

In this study I addressed the following questions about interactive whiteboard usage in secondary mathematics classrooms:

How do teachers use an interactive whiteboard to elicit student thinking in a secondary mathematics classroom?

- Which IWB features do teachers and students use?
- How do teachers intend to use and actually use these IWB features to elicit student thinking?
- How do teachers elicit student thinking when students use these IWB features?

CHAPTER 2

LITERATURE REVIEW AND THEORETICAL PERSPECTIVES

I organized this chapter in a way that provides a review of the literature detailing scholarship on foundational topics relevant to my exploration of IWB usage: instructional technology, mathematics education, and whole-class discussion. Because the study explores teachers' decisions on how to use IWBs to elicit student thinking, I situated the study within two complementary frameworks. I believe these frameworks offer a way to view teachers' decisions that involve sharing the interactive whiteboard (IWB) with their students for exploring mathematics.

Review of Literature

I have situated this study in relevant research regarding how secondary mathematics teachers have used IWBs to support their instruction by organizing this literature review consistent with the evolution of the merging of technology with education over the last two decades. With the mainstream deployment of IWBs taking place no sooner than the 1990s, scholarship on this subject is fairly recent. First, I provide a lens into the nature of how researchers examined teaching with technology. The themes and frameworks identified in this time period offer a foundation for researchers to later explore content-specific scholarship focusing on how IWBs can influence mathematics instruction. Next, I present a review of the research landscape describing the dynamics of whole-class discussion as a form of classroom instruction. Consistent with how teachers use interactive whiteboards as a whole-class instructional tool, I share research findings that offer perspectives on how teachers use IWBs to support their pedagogical strategies. After this discussion, I hone in on a review of scholarship describing how the research community has explored teaching mathematics with technology. Last, I conclude this review with an overview of research describing teaching mathematics exclusive to interactive whiteboards. Throughout this literature review, I offer a variety of models detailing technology use in terms of teacher strategies, pedagogical classifications, and classroom adoption processes.

Teaching with technology. During the late 1990s, the topic of *teaching with technology* surfaced in the research community with discussions on how technology in the classroom provided a potential means to the enactment of educational reform. A great deal of interest centered on how technology might serve to foster more student-centered instruction (Means et al., 1995). Even though researchers referenced the act of *teaching* as an aspect of their studies' designs, they did not necessarily envision the actual teacher as a component of these studies. In some cases, the research questions hinged on how digital technologies such as desktop computers or videodisc players served to improve student learning apart from the teachers' pedagogy.

An illustrative example of this genre of research includes the Jasper Woodbury Problem Solving Series developed by the Cognition and Technology Group at Vanderbilt (CTGV). Technology-based instruction took the form of a set of video-based instructional adventures. Teachers facilitated student-learning activities that provided a realistic context for mathematics and science problem solving. This prestigious research team explored various instructional designs with a goal of identifying evidence of generative learning (CTGV, 1992). I offer this example of a technology-centered research program to illustrate the integration of both teaching and learning, where the primary source of instruction is technology, not a teacher.

A prevalent contribution to the body of research on teaching with technology was the introduction of frameworks designed to classify teacher roles and concerns in addition to the variety of technology-functionalities these teachers could incorporate into their daily responsibilities. The first two of these frameworks represent developmental models in which teachers may or may not reach the final phase. The third framework offers an evaluative tool for classifying technology functionalities.

Teacher roles with technology. Hooper and Rieber (1995) explored the stages of technology adoption in education referencing a comparison between a traditional classroom and a future version. Their discussion highlighted a simplified form of a five-stage model that maps educators with their functional role involving technology adoption: (1) familiarization, (2) utilization, (3) integration, (4) reorientation, and (5) evolution. Teachers must traverse all five stages in order to realize the full potential of a chosen technology (Marcinkiewcz, 1993/94; Rieber & Welliver, 1989). The first phase, familiarization, occurs when a teacher initially sees or hears of a new technology. The next two phases involve teachers' initial experimentation with and commitment to the technology as a part of their established instructional toolkit. Teachers who reach the remaining two phases, reorientation and evolution, demonstrate student-centered pedagogical decisions directed at the establishment of a "learning environment that supports and facilitates students as they construct and shape their own knowledge" (Hooper & Rieber, 1995, p. 4).

Teacher concerns about technology. Teachers exercise judgment and concern with how they use any instructional tool. Consistent with their Stages of Concern model for assessing innovation adoption, Hall and Hord (2011) described three types of concerns teachers have when implementing technology: (1) self concerns, (2) task concerns, and (3) impact concerns. Within each of these three stages are substages presenting further refinement of the subject's nature of concern. Progression through these stages is not assured as the environment for teaching involves other factors such as school leadership and access to relevant professional development, which might impede advancement through this adoption process. Teachers who are experiencing concerns in the first stage become aware of the technology and assess the potential value it might offer to their instructional goals. Teacher concerns representative of the second stage reflect a focus on learning how to operate the new digital equipment or software. The third stage reflects teachers engaged in student-centered pedagogical decisions and actions. It is this final stage where teachers view the technology as a means of supporting their students' learning.

Technology's instructional functionality. Not all implementations of educational technology are equal. Jonassen, Peck, and Wilson (1999) warned, "The ways that we use technologies in schools should change . . . from their traditional roles of technology-as-teacher to technology-as-partner in the learning process" (p. 12). Jonassen, et al. (1999, p.13) developed a framework for how technologies foster learning. In line with constructivist theory, learning should occur *with* technology, not *from* technology. Technology in support of student learning would include the following roles:

- tool to support knowledge construction
- information vehicles for exploring knowledge
- context to support learning-by-doing
- social medium to support student learning by conversing
- intellectual partner to support learning-by-reflecting

This conceptual framework of classifying educational technology provides teachers with a means to evaluate the various ways in which learning with technology takes place in the classroom.

Teaching with whole-class discussion. Because the IWB is a relatively large piece of equipment designed for full class viewing, I have provided a review of the research on whole-class discussion to further frame this study's methodology, analysis, and findings. Similar to the previously described theme on *teaching with technology*, I believe a review of the literature on *teaching with whole-class discussion* suggests an emphasis on student-centered instruction. Various studies label this form of instruction as interactive, community-based, and multilayered (Freedman & Delp, 2007; Wood, Cobb, & Yackel, 1993). Students engage in a learning space by "responding to it, constituting it, shaping and reshaping it, and influencing [the] ongoing structure of it" (Freedman & Delp, p. 262) where teachers guide the whole-class conversations "as multimodal reflective thinking texts that unfold on an interpersonal phase of learning" (Shreyer, Zolkower, & Perez, 2010, p. 50). Consistent with the multimodal ways teachers and students interact with IWBs, researchers defined these thinking texts as either "spoken, written, diagrammed, or all of the above" (Shreyer et al., p. 26). Thus, this conversational (text) mode of whole-class discussion supports student engagement in a group think-aloud discourse.

Although researchers claim whole-class discussion can emphasize student-centered learning, this reform-driven pedagogical characteristic is offset by the limitation that only a few students can verbally expose their mathematical thinking at one time in the dialogic learning space (Margolin & Regev, 2011). Otherwise, whole-class discussion becomes whole-class chaos. Similarly, other researchers described the nature of this form of classroom discourse as a learning environment where actively involved students express their explanations, justification, and elaboration that result in a complex and reflexive process, sometimes creating dilemmas for teachers (Wood et al., 1993). Upon reviewing the literature published in the past decade, I found several pedagogical models that offer strategies for how to optimize whole-class discussion in light of this limitation.

How to facilitate student-centered whole-class discussion. One pedagogical model identifies five key practices to productively facilitate whole-class discussions involving student responses to student-centered instructional tasks (Stein, Engle, Smith, & Hughes, 2008): (1) anticipating, (2) monitoring, (3) selecting, (4) sequencing, and (5) making connections. In anticipation of students approaching a problem in a variety of ways, the first practice involves teachers exploring the problem with multiple solution strategies. By taking this proactive effort, the teacher is better poised to anticipate potential misinterpretations or confusion. The second practice requires that teachers physically situate themselves to view and hear students' efforts to explore and solve problems. Students expose their mathematical thinking when engaged in particular learning activities. Third, teachers can strategically select students whose individual problem-solving efforts serve to facilitate discussion aligned with a preset instructional goal. Fourth, teachers make purposeful choices about the order in which the whole class sees the selected students' approaches. Depending on the instructional goal, teachers may want students to discuss a solution strategy that favors a particular connection. Fifth, as the culminating practice, teachers leverage the types and order of the various problem solutions in a manner that leads their students toward specific connections.

Features of whole-class discussion competence. Another pedagogical model (Ball, Sleep, Boerst, & Bass, 2009) lists four features detailing competent facilitation of whole-class discussion: (a) mathematically sound task accessible to all students, (b) quick and eventual understanding, (c) teachers' multiple and varied approaches to engage numerous students in central mathematics, and (d) a focus on meaningful connections to preceding discussion and subsequent learning experience. Each of these competencies maps onto the five practices presented previously in the model developed by Stein and colleagues (2008). For example, the *anticipating* practice is similar to the first competency feature of accessibility because they both involve teachers exploring multiple solution paths. Another parallel between these two models occurs between the *monitoring* and *sequencing* practices and the feature involving *quick and eventual understanding*. Because teacher decisions are purposeful, this parallel reflects the perspective that the type and the order of solutions enhance students' learning. Similarly, the fifth key practice of *making connections* clearly maps to the fourth competence feature as they both use nearly the same descriptions.

Teacher mediation strategies. A third model of relevance to this study details a list of mediation strategies for teachers to consider when facilitating meaningful mathematical discourse. These strategies specify that teachers: (a) enable multiple ways of thinking, (b) insist upon accurate language, (c) anticipate and expose misconceptions and mistakes, (d) use visual mediators to demonstrate concepts and ideas, and (e) redirect student questions for clarification or explanation to whole-class discourse (Margolin & Regev, 2011). This list offers teachers a reasonable amount of latitude for interpreting the specific ways they would engage students when facilitating whole-class discussion. Although this model is similar to the first one in that they both describe teacher efforts, this mediation-oriented model on key practices (Margolin & Regev, 2011) is less prescriptive. For instance, the first model promotes a pedagogical process involving multiple steps as opposed to a list of mediation strategies for teachers to consider individually or in combination.

Teaching mathematics with technology. Consistent with the literature on generalized teaching with technology, researchers who narrow this topic specifically to mathematics emphasize that technology is a tool or mediator (Fey, Hollenbeck, & Wray, 2010; Heid, 1997; Peressini & Knuth, 2005). By placing this caveat on their findings, they position the teacher as having control over whether change occurs or not. Furthermore, some researchers have attempted to tie technology implementation to NCTM's reformed vision of a mathematics classroom (Peressini & Knuth, p. 205). In particular, several studies described this form of pedagogical technology implementation as one that changes the classroom dynamics. Heid (1997) illuminated this transformation stating, "The structure of classroom activities as well as the ways in which teachers and students interact have changed" (p. 37). In particular, Heid explained that student "learning became more visible and teachers could see and assess more facets of the problem-solving process" (p. 39). This transformed classroom dynamic embodies *conceptual conversations*, a term used to describe student discussion that minimizes a focus on procedures and favors a learning environment where mathematics discourse centers on relationships, images, and explanations (Thompson, 1996).

According to NCTM (2000), mathematical *connections* and *representation* are two of the ten standards associated with effective mathematics instruction. Mathematics represents a subject area composed of numerous interrelated concepts in which various representations offer a way of seeing similarities and difference between these connections. Hollenbeck, Wray and Fey (2010) described this view explaining, "Manipulating equations and expressions into alternative equivalent forms often leads to solutions for problems and insight into relationships. Computer simulations and calculation tools can help students develop understanding of the concepts and skills involved in those processes" (p. 271). From this perspective, teachers can use technology in the mathematics classroom to foster student exploration that includes more dimensions of a single problem and its solution than otherwise accessible. By placing a digital spotlight on the connections between and among these mathematical representations, students can interact with the mathematics on their own terms.

Various pedagogical models offer parallel views on how teachers can recognize technology in terms of pedagogical value, use, and strategies. I have reviewed three such models as relevant to my study. In each of these models, the researchers consistently emphasized technology in accordance with student-centeredness, mathematical connections, and mathematical representations.

Synergistic principles. In this first model, researchers described technology as an instructional tool that can shape a mathematics classroom into a dynamic learning environment. In support of this vision, Heid (1997) outlined four synergistic principles that characterized teacher values for the use of technology in mathematics education: (a) Technology can help teachers realize a student-centered learning environment; (b) Technology can provide students with the experience of being a mathematician; (c) Technology can support learning by promoting reflection; (d) In technology-intensive instruction where technology tools are shared between the teacher and the students, so is the epistemological authority. This set of principles illustrates a mindset toward the benefits and advantages a mathematics teacher can harness with technology. The synergy among these four principles occurs because students are the central factor in determining how technology supports teaching and learning.

Operational and pedagogical thinking. In contrast to the previous model, Ruthven and Hennessy (2002) studied teachers' pedagogical thinking in seven English secondary schools with successful deployments of technology in support of teaching and learning mathematics. These researchers organized their findings in the form of a pedagogical model composed of ten operational themes and two pedagogical themes. Of particular interest were the themes portraying technology with these particular characteristics: (a) tinkering assisted (self-correction by students), (b) engagement intensified (deeper and stronger engagement in classroom work), (c) activity effected (whole class pace and productivity), (d) features accentuated (vivid images and striking effects), and (e) attention raised (better focus of students' attention on overarching ideas and processes). These five themes provide a strong linkage to the nature of how teachers use IWBs in support of learning mathematics. Specifically, these themes emphasize whole-class discussion that is student-centered and interactive, and that promotes mathematical connections and multiple representations.

Pedagogical tool functionalities. A third model classifies a variety of professional functions an educational tool can provide to the teaching practice. Among the five tools presented by Peressini and Knuth (2005), I believe IWBs take the form of a cognitive tool because this form provides teachers with a means to incorporate technology into their instruction in which students explore and engage with the mathematics.

Teaching mathematics with interactive whiteboards. Unlike personal computers, the IWB is a type of digital equipment considered to be "the first electronic instructional technology designed primarily for use by teachers" (Betcher & Lee, 2009, p. 5). The IWB provides users with a digital platform to more fluidly interact with text, images, and video. Glover and Miller (2001) described the interactive whiteboard:

> Theoretically, the interactive whiteboard is more than a computer, a projector or a screen—its sum is greater than its parts. . . . It can enable the teacher to use high-quality material previously prepared by a teacher or group of teachers using software packages; to use multimedia including electronic microscopes, video clips, board work, data tables, sketches, CD-ROM, or Internet images; and facilitates simulation activities incorporating student input and reasoned discussion, and immediate recording of the contents of the board at any stage in the development of an argument. (p. 258)

My review of the literature focusing on educational technology specific to the field of mathematics education indicated that most equipment-specific research centered on exploring the learning benefits to the individual student. Such devices include graphing calculators, dynamic geometry software applications, and computer algebra system (CAS) tools. These particular devices typically offer an interface designed to support a single user. I have witnessed teachers attempting to expand the learning experience beyond the individual student by either designing activities requiring students to work in small groups or projecting these computer applications on a static whiteboard mounted in the front of the classroom. Although pairs of users can reasonably explore mathematical concepts on a single device, only one person can actually interact with the device at a given moment. Similarly, a single user can share his or her computer-generated mathematics representation with an entire class using an LCD projector. The difference resides in the nature of interaction. In this scenario, the equipment's user interface (typically a keyboard or mouse) supports only a single operator.

In contrast, the IWB is a type of educational technology that allows for a whole-class interactive learning experience where multiple users have access to the manipulation of the mathematics in a variety of practical ways. In spite of the need to take turns using the IWB, this pedagogical tool provides a large physical workspace for multiple participants to view and discuss the mathematics. Alternatively, teachers can strategically engage multiple students in a whole-class exploration by projecting multiple student work samples throughout the class discussion in a manner that is both easy and timely.

Pedagogical use of interactive whiteboards. When exploring how teachers can use this digital device as a pedagogical tool, an understanding of its available functionalities is necessary. Effective integration of this technology into a teacher's lesson plan requires planning that considers both the interaction between the technology and the mathematical content as well as the interaction between the technology and the pedagogy. Specifically, when formulating a lesson plan that incorporates technology tools, the teacher needs to take into account the nature of the student learning objective when choosing *which* technology features to use, in *what order* the class will use these features to investigate the mathematics, and *how* the class will interact with the technology to explore these concepts.

Consistent with many lesson-planning decisions, teachers should take into account relevant student misconceptions to optimize student understanding. I believe a benefit of including technology in a mathematics classroom is that teachers can orchestrate an interactive learning experience emphasizing strategic repetition and variation that can minimize misconceptions. Kent (2006) described this teaching approach as one that integrates technology with both pedagogical decisions and content knowledge stating,

> In a mathematics teaching context, teachers with an IWB now have a wider range of [educational technology] possibilities available to support their teaching. . . . The teacher still manages the learning environment [by] leading the discussion, posing questions, [and] responding to student suggestions. (p. 24)

Research study findings have just begun to illuminate how teachers use IWBs as a pedagogical tool. By examining the ways teachers make use of the various IWB features throughout the classroom learning experience, future studies will reveal how teachers gain new insights into their students' understanding or misconceptions of mathematics. These types of insights may be deeper in nature and possibly representative of more students than has been possible previously. Such findings could offer insights into whether different technology features, individually or in combination, provide different advantages to specific mathematical content areas or styles of teaching. The research findings of Miller, Glover, and Averis (2005) are the beginnings of a description of some of the ways teachers may take advantage of what the

IWB offers by maximizing interactivity among themselves, the pupils, and the learning materials. Findings from the Miller et al. study suggested that the teachers achieved a more interactive whole-class learning experience by

> exploiting opportunities for manipulation by teacher and pupil during lessons; . . . extend[ing] use of immediate feedback from software; using strategies for shared evaluations; [taking] the opportunity for [the] differentiation of materials on the [IWB]; and using the [IWB] as a focus and catalyst in lessons. (p. 108)

Models for teaching with an interactive whiteboard. The extant body of research on teaching and learning with interactive whiteboards continues to grow. Among the numerous articles published on this subject, several models have emerged that describe: (a) how teachers evolve in their usage of the IWB, (b) what ways teachers use the technology, and (c) reasons to use and not to use the equipment. Not only do these articles offer studies focused on teaching mathematics, they investigate this subject matter at the elementary and high school levels.

Teaching trajectory model. Unfortunately, just knowing how to operate IWB features does not result in an effective interactive whole-class learning experience. The research literature indicates that teachers experience a learning curve trajectory in order to capitalize on the pedagogical benefits associated with an IWB-equipped classroom. This trajectory follows a three-phase developmental progression characterized by the ways teachers use the IWB to support their instructional goals (Betcher & Lee, 2010; Miller, Glover, & Averis, 2004):

- Phase 1 (Supported Didactic): Teachers adapt lessons they have always done (old methods in old ways) to the IWB.
- Phase 2 (Interactive): As they become more confident with the technology, they revise their current practice in ways that incorporate interactivity (old methods in new ways).

- Phase 3 (Enhanced Interactive): As they master the IWB features, they gradually present lessons in sophisticated, highly interactive ways (new methods in new ways).

Miller, Glover, and Averis (2005) reinforced this model by explaining that in order for teachers to take advantage of all that an IWB has to offer, they need to maximize interactivity among themselves, the pupils, and the learning materials. Teachers achieve this level of effective IWB mathematics instruction through "the extended use of immediate feedback from software; the use of strategies for shared evaluations; the opportunity for differentiation of materials on the [IWB]; and as a focus and catalyst in lessons" (p. 108).

Feature/functionality classification. Kennewell and Beauchamp (2007) proposed a two-level taxonomy of educational technology features (also referred to as functionalities) in which they further analyzed how teachers and students used the IWB for three core subjects (English, mathematics, and science). In their study, this research team explained,

> Teachers used the IWB software for focusing learners' attention on salient features of the task and content—labeling, highlighting, colour coding, classifying—for revisiting key points during the reflective review at the end of the lesson. It was common for students to be keen to come to the board to write up ideas or drag an item into an appropriate position. (p. 234)

In analyzing a mathematics lesson, Kennewell and Beauchamp (2007) listed some of the IWB functionality types such as *accuracy*, *list*, *provisionality*, *library*, and *feedback*. They explained that teachers' instructional decisions translated into various IWB functionalities that map to "classes of action perceived as affecting learning when supported by [educational technology]" (p. 239). For example, they explained that accuracy (using IWB highlighting) allows for the construction of items "with greater precision than is realistic manually" and noted that feedback (using IWB flipcharts) assists teachers with "the ability to respond to user input contingently" (p. 233).

The concept of IWB feature classification is not unique to Kennewell and Beauchamp. For instance, Tanner and Jones (2007) preferred one set of IWB features to another when assessing sustainable educative value. These researchers claimed,

> Initially, it is the surface features of the IWB that are valued, such as pace, accuracy, involvement and motivation. However, reports of increased motivation and attention, following the introduction of [educational technology], have a long history and tend to be transitory as novelty wears off. It is the deeper features, such as automation, editability, transformability and feedback that are likely to offer value that is more permanent. These offer the potential for more sustained engagement, during which interaction that is more substantial might prove possible, leading to increased momentum in lessons and deeper understanding of mathematics. (p. 40)

Theoretical Perspectives

A review of the literature offers a perspective on how the mathematics education community views IWBs as a pedagogical tool. Because I explored teachers' decisions about how to use the IWB, I situated the study's design in frameworks that explicitly reflect the dynamics of the classroom experience. Specifically, I grounded this study's design in two frameworks: Cobb and Yackel's (1996) *emergent perspective*, a sociocultural framework that limits the cultural relevance to the confines of the mathematics classroom, and Mishra and Koehler's (2006) technological pedagogical and content knowledge framework, a model of technology integration in teaching and learning that "requires a thoughtful interweaving of all three key sources of knowledge: technology, pedagogy, and content" (p. 1029). By using both frameworks, my study design situated the *mathematics* teacher's decisions and actions of how to use interactive whiteboards within the *pedagogical* intentions of eliciting student thinking.

Connections to sociocultural theory. Various learning theories of cognitive development have offered selective lenses into how students learn new concepts. Specifically, Lev S. Vygotsky, the Russian psychologist, developed a theoretical framework about learning and instruction that places an emphasis upon "the social and cultural context within which such development is embedded" (Driscoll, 2005, p. 247). According to van Oers (2004), "Sociocultural theory has become a powerful and competing paradigm in today's landscape of social and cultural sciences. The core of the sociocultural theory goes back [to] the ideas of Vygotsky who developed his cultural historical theory of human development" (p. 1). Similarly, Scott and Palincsar (2010) summarized the goal of sociocultural theory as a way to explain "how individual mental functioning is related to cultural, institutional, and historical context" (para. 1).

Even though the research literature on IWBs emphasizes the concept of *sharing* as a component of the classroom learning experience, I found only a few explicit descriptions about the nature of this sharing. On the contrary, I identified several implicit references to how users share an IWB. For example, Tanner and Jones (2007) stated,

> Control of the teaching and learning process must be *shared* [emphasis added] with the pupils if deeper levels of interaction are to be achieved. In such circumstances, the full technical interactivity of the IWB can be utilized in support of learning. The IWB can act as a *communal* [emphasis added] PC for exploration and co-construction of knowledge by the class as a whole. The speed and ease with which multiple examples can be generated and contrasted with alternative representations can help pupils to speculate and generalize. In these ways, the IWB may provide a *public* [emphasis added] forum for debate and *collective* [emphasis added] reflection on tentative work in progress. (p. 40)

Tanner and Jones intentionally used terms such as *shared, communal*, *public*, and *collective* to describe the social nature of the classroom experience representative of their research findings. It is this view of social environment that has informed my thinking and led me to adopt sociocultural theory as a framework for my study. In further support of this theoretical direction, my focus on classifying an IWB as a pedagogical tool is consistent with the tenets of Vygotsky's (1978) sociocultural viewpoints on learning through the mediation of tools. Vygotsky (1978) explained, "The tool's function is to serve as the conductor of human influence on the object of activity; it is *externally* oriented; it must lead to changes in the object" (p. 55).

Mediation is a primary tenet of Vygotsky's sociocultural theory. According to Lantolf (2000), Vygotsky defined *mediation* as the act of establishing an indirect relationship between the world and one's self. Lantolf explained, "Vygotsky argued that just as humans do not always act directly on the physical world, [they] rely instead on tools and labor activity . . . [allowing] us to change the world . . . and the circumstances under which we live" (p. 1). The message here is that Vygotsky put significant capital into his theory's claim that humans have used tools as mediators to generate a desired result. I believe the whole class interactive learning experience involving an IWB has the potential to present an example of Vygotsky's views of mediation in sociocultural theory.

Of equal importance to Vygotsky's definition of sociocultural theory is his description of humanity's tools as being connected both culturally and historically to their users. Here I draw a distinction between the scope of Vygotsky's theory and the limited focus of my research questions. Although I value the cultural and historical perspectives of each classroom participant, I honed my focus exclusively upon the social interaction that takes place within the secondary mathematics classroom. This classroom-only scope of study is not consistent with Vygotsky's sociocultural framework; rather it significantly aligns with the tenets of the *emergent perspective* (Cobb, Jaworski, & Presmeg, 1996; Cobb & Yackel, 1996). Cobb and Yackel (1996) clarified their emergent interpretative framework as one that

> considers students' mathematical activity to be social through and through because it does not develop apart from their participation in communities of practice. More generally, [the] intent is not to classify teachers' and students' activities into those that are intrinsically individual and those that are intrinsically communal. Instead, [their] proposal is to *coordinate* analyses of classroom practices that are conducted in psychological and social terms. (p. 180)

Emergent perspective framework. Cobb and Yackel (1996) presented their interpretative framework as developmental research, defined as a cyclic model combining instructional development and classroom-based research (Gravenmeijer, 1994). Moreover, they explained this framework as one that “coordinates psychological constructivism with interactionism, . . . [where] the focus is on patterns and regularities in [all classroom participants’] interactions and on the consensual meanings that emerge between them rather than on the students’ personal interpretations” (p. 184).

Cobb and Yackel (1996) described this framework as two perspectives, each having its own set of constructs. Within the first, *social perspective*, these researchers “denote three aspects of the classroom microculture that [they] found useful to distinguish” (p. 177). The second, *psychological perspective*, contains a “list [of] the psychological constructs that [they] take to be the individual correlates of these social constructs” (p. 177). Cobb and Yackel (1996) deliberately used the concept of *correlation* as they described a reflexive relationship between the two perspectives within this framework. Furthermore, they explicitly stated, “Neither the social norms nor individual students’ beliefs are given primacy over the other. . . . Instead, social norms and beliefs are to be reflexively related such that neither exists independently of the other” (p. 178).

Cobb, Jaworski, and Presmeg (1996) extended this differentiation between sociocultural and emergent theorists by claiming that they viewed the former as individuals-in-social practice, whereas they saw the latter as individuals jointly adapting to each other’s interactional routines and patterns. Further elaborating on this reflexive relationship, Cobb et al. (1996) stated, “From this latter perspective, the link between sociocultural and cognitive processes is indirect and is accounted for in terms of the opportunities for conceptual construction that arise as students participate in classroom activities” (p. 15).

I framed the study with the emergent perspective because it maintains a connection to a classroom microculture. I believe the nature of the established classroom culture has an influence on IWB usage. Tanner and Jones (2007) provided such a connection as they distinguished the source of classroom interactivity as being

> more a function of the ethos of the classroom and the strategies employed by the teacher than the tool employed. However, the IWB can be used effectively in this context, allowing pupils to come out to the board and reproduce earlier examples quickly in discussion and allowing the teacher or pupils to focus attention on key points. (p. 41)

The emergent perspective framework guided me in exploring how teachers recognize social learning structures within the classroom when teachers and/or students are exploring mathematics. This framework provides a perspective that whole-class discussion relevant to IWB usage in a classroom can expose students' understanding of mathematics. Using this view, I explored patterns in how teachers interpreted their IWB usage when sharing the mathematics.

Technological pedagogical and content knowledge framework. Historically, researchers have explored both teachers' content and pedagogical knowledge in support of designing and evaluating effective teacher education and professional development programs. The integration of these two domains later became the area of much focus when Shulman (1986) introduced the idea of pedagogical content knowledge (PCK). With the inclusion of digital technologies into Shulman's teacher-knowledge framework, his framework evolved to encompass a third form of knowledge that addressed the domain of digital technology.

Mishra and Koehler (2006) defined this expanded framework to include digital technology as one of three overlapping domains of teacher knowledge. This framework emphasizes the complex interplay among the knowledge domains of content (C), pedagogy (P), and technology (T). As presented in Figure 1, Mishra and Koehler (2006) have referred to the innermost intersection of the three knowledge domains as technological pedagogical and content knowledge (TPACK). This particular intersection represents a type of knowledge that

> requires an understanding of the representations 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; [and] knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (p. 1029)

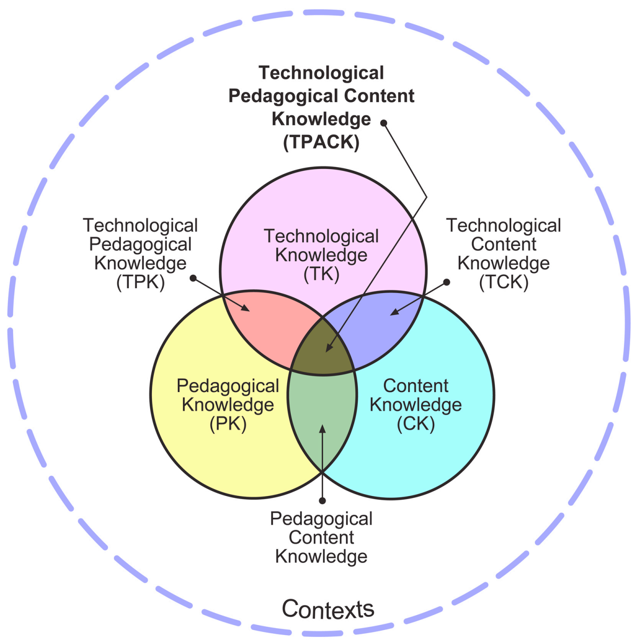

Figure 1. Technological pedagogical and content knowledge. This figure illustrates a teacher knowledge model representing various intersections relevant to technology, pedagogy, and content. *Note.* From www.tpack.org. Copyright 2011 by M. J. Koehler. Reprinted with no permission required for nonprofit works.

To help teachers optimize the benefits of educational technology in the mathematics classroom, researchers need to investigate how the intersection of these different types of teacher knowledge plays out in the classroom when using technology.

Mishra and Koehler (2006) portrayed teaching and learning with technology as a dynamic transactional relationship whereby "a change in any one of the factors has to be 'compensated' by changes in the other two" (p. 1030). Thus, this triad is both complex and nuanced. With the introduction of technology to a teacher's pedagogical toolkit, this technology often imposes its "own imperatives that constrain the content that has to be covered and the nature of possible representations" (Mishra & Koehler, p. 1025). This dynamic highlights an increased complexity imposed upon the teacher when attempting to integrate TPACK-minded decisions into the lesson-planning process. By modifying the student's learning experience to include the involvement of educational technology, teachers would be wise to revisit their established pedagogical decisions. Technology integration warrants a deeper consideration of how students will use the equipment features in ways that support the lesson plan's learning objectives.

The TPACK framework provided me with a structured analysis tool for deconstructing my data to identify and examine teacher intentions to elicit student thinking. I realize many experienced teachers use their recall of classic misconceptions and their instincts to process student progress toward mathematical understanding. Because my participants were prequalified as moderate to extensive IWB users, I believe the TPACK framework provided me with an appropriate analysis tool to deeply explore my data in terms of the frameworks' various knowledge domains.

CHAPTER 3

METHODOLOGY

I used a multi-method qualitative research design involving a two-phase process: (1) prequalification of participants using teaching and IWB experience level in addition to student-centeredness and (2) multiple data collection cycles of video-stimulated recall (VSR) interviews. This research design approach is consistent with the characteristics of qualitative research presented by Creswell (2009): (a) natural setting, (b) researcher as key instrument, (c) multiple sources of data, (d) inductive data analysis, (e) participant's meanings, (f) emergent design, (g) theoretical design, (h) interpretative, and (i) holistic account.

Research Design Rationale

My research objective was to identify patterns and themes reflecting how secondary mathematics teachers used IWBs as an instructional tool. I accomplished this goal by examining teachers' perspectives as a function of their classroom experiences. By formulating a research design that emphasized video-stimulated recall (VSR) interviews, I had a data collection method that enabled participants to recall previous classroom experiences more accurately through the use of audio and visual memory triggers. The VSR data collection technique addresses a participant's capacity for "direct reporting of introspective reasoning and the need to maximize the subject's use of short-term working memory" (Lyle, 2003, p. 862).

Specifically, I examined the relationship between teacher decisions and their use of IWBs to elicit student thinking. Because experienced teachers tend not to formalize their lesson plans in a summarized written format, I focused on how teachers enacted their lessons. Consistent with the theoretical perspectives of Cobb and Yackel's (1996) *emergent perspective* framework (sharing the IWB) and Mishra and Koehler's (2006) TPACK framework (using technology in support of specific pedagogically driven efforts to learn mathematics) as detailed in Chapter 2, I explored teacher decisions involving the sharing of the IWB with and among the students. This sharing includes both (a) who has actual physical control of the IWB and (b) who leads the exploration of mathematics using the IWB.

Participant Selection

I used a stratified sampling strategy in order to target participants who had adequate experience in both secondary mathematics teaching and IWB technology usage and a predisposition for using student-centered instructional techniques. I purposefully selected the initial pool of 4 participant-candidates through either personal or professional contacts. Using a snowball-sampling (Patton, 2002) referral process, I secured the remaining 11 participant-candidates by asking the initial candidates to offer leads on new ones. Of the original 15 candidates, 6 participants declined, citing lack of time to commit to data collection events or personal views of incompatibility with study focus. Additionally, I excluded one candidate after the first interview because I determined she had no prior experience teaching her current course using an IWB. My final sample consisted of 8 prequalified participants.

Qualifying participants. Although there is instructional significance relating to *which* IWB features a teachers uses, the nature of *how* the teacher uses these features in various ways or combinations to facilitate a learning environment is what defines a lesson as being interactive and dynamic (Betcher & Lee, 2009; Kennewell & Beauchamp, 2007; Tanner & Jones, 2007). Without such experience, participants are more likely to be operating at the novice level when it comes to exploring the technology's capabilities. To adequately investigate my research questions' focus, I prequalified this sample's IWB usage for teaching experience, student-centered pedagogical disposition, teacher concerns, and teacher behavior.

Teachers use IWBs to support their instruction in a variety of ways. This range includes intentions: (a) to address specific learning styles, (b) to streamline information dissemination, (c) to reorganize content, and (d) to infuse novelty. Given this spectrum, I established a criterion for participant selection favoring student-centered learning. For instance, it is not uncommon for some teachers to "fall into the trap of slavishly following someone else's lesson plans" (Tanner & Jones, 2007) that involved an IWB used merely to deliver another teacher's PowerPoint presentation. By administering a pre-qualification instrument in the form of a concerns-based questionnaire, I minimized subsequent data collection efforts involving participants who did not fit the purposeful sample profile. I more fully describe this paper-and-pencil instrument in the section that follows.

Qualification based on experience. As the first step to qualifying participants as being more seasoned IWB-savvy teachers, I selected candidates who possessed at least 3 years of teaching experience. The requirement of 3 years aligns with the estimates provided by Steffy and Wolfe (1998) in their description of a career teacher's lifecycle. As described in their developmental model, teachers with 3 years of experience have emerged from the *apprentice* phase (student teaching through the inductive years of teaching) and are demonstrating engagement in their practice at the subsequent *professional* phase. At this phase teachers view themselves as student advocates, characteristic of teachers for whom "student feedback plays a critical role" (Professional Teacher section, para. 1) in carrying out their responsibilities as educators.

To further secure qualified participants, I used criterion sampling as a way of excluding teachers who limited their IWB use to teacher-centered instructional efficiency. Betcher and Lee (2010) described teachers with greater IWB experience as being highly interactive. They elaborated upon the nature of teachers' evolving IWB use in this phase explaining, "As new approaches to teaching become apparent, . . . so does the need grow to build related technology skills such as working with digital images, effectively searching the web, manipulating audio and video, [and] discovering new software applications" (p. 53).

Because teachers typically experience a developmental journey (Betcher & Lee, 2010; Miller, Glover, & Averis, 2004) in learning how to use IWBs, I also took into consideration the criterion that my research participants needed to have at least 3 years of IWB experience. I rationalized my application of Miller and colleagues' (2005) developmental cycle by considering the linkage between teachers' efforts to take advantage of all that an IWB has to offer with their efforts to maximize interactivity among themselves, the students, and the learning materials.

Qualification based on stage of concern. In the second phase of the participant qualification process, I administered a modified version of Hall and Hord's (2011) 35-item Stages of Concern (SoC) questionnaire designed to classify innovation users as having attitudes representative of a particular stage considered to reflect student-centered perspectives. The particular innovation for my study was the adoption of an interactive whiteboard as a pedagogical tool in support of learning mathematics.

Expanding on the research of Frances Fuller (1969) with the development of a concerns-based adoption model (CBAM), Hall and Hord (2011) identified and confirmed a set of seven specific categories of concerns about innovation adoption, referred to as Stages of Concern. My main purpose for using this SoC questionnaire was to classify users (teachers) of an innovation

(IWB) by their relevant instructional concerns. Specifically, I wanted to identify participants who demonstrated higher levels of Hall and Hord's fourth SoC, titled *Consequence*. George, Hall, and Stiegelbauer (2008) defined the consequence stage of concern:

> The individual focuses on the innovation's impact on students in his or her immediate sphere of influence. Considerations include the relevance of the innovation for students; the evaluation of student outcomes, including performance and competencies; and the changes needed to improve student outcomes. (p. 8)

This particular stage represents the minimum classification category acceptable for my goal of exploring teachers' decisions about how to make use of an IWB with the intent of eliciting students' mathematical thinking.

Qualification based on levels of usage. Because participants may express a concern, yet not actually engage in teaching practices consistent with that concern, I further qualified participants with the support of a second instrument focused on IWB behaviors. I administered a semi-structured version of the CBAM Levels of Usage (LoU) interview protocol to gain insight into participants' recollection of how they used the IWB in a prior lesson. I used this interview protocol to further probe participants' self-reported efforts to use the IWB as an instructional tool.

This additional effort resulted in my decision to reconsider 2 participants with low to moderate SoC scores and strong LoU scores. For example, one of these participants answered the SoC question about students' attitudes and teacher impact with the lowest ranking option while expressing highly ranked perspectives consistent with the Consequence LoU stage intended to reflect behavior geared toward improving student learning outcomes (Hall, Dirksen, & George, 2008). Because no single research tool guarantees absolute conclusions, I believe these additional participants offered behavior-based views that were consistent with my research goals.

Settings

The settings for this study included eight secondary mathematics classrooms located in three high schools in the southeastern United States. The participants' classrooms sizes ranged from 14 to 37 students, with subject matter including algebra, geometry, and advanced algebra (precalculus). The participants taught secondary mathematics content to students at a variety of learning levels (extended time, on-level, and honors-level) with students ranging in grade levels from Grade 9 through Grade 12. The eight classroom technology settings included a variety of IWB configurations. Five classrooms used SMART boards (SMART Technologies, 2013), one used a Smart Sympodium (podium based IWB, SMART Technologies, 2013), and two used an ActivBoard (Promethean World Plc, 2012).

Primary Methods of Data Collection

Creswell (2009) explained, "Qualitative researchers typically gather multiple forms of data, . . . rather than rely on a single data source . . . [in which they] make sense of it, and organize it into categories or themes that cut across all of the data sources" (p. 175). Consistent with this characterization, I explored the nature of participant instruction involving IWBs in mathematics classrooms by integrating sequenced interviews (Seidman, 2006) with multiple data collection cycles of video-recorded classroom observations (Pirie, 1996). By combining the data collection methods of interviews, observations, and supporting documents, I gained access to an extensive data corpus that spanned the full range of my research questions. In Figure 2, I present a graphical representation of the overall data collection process.

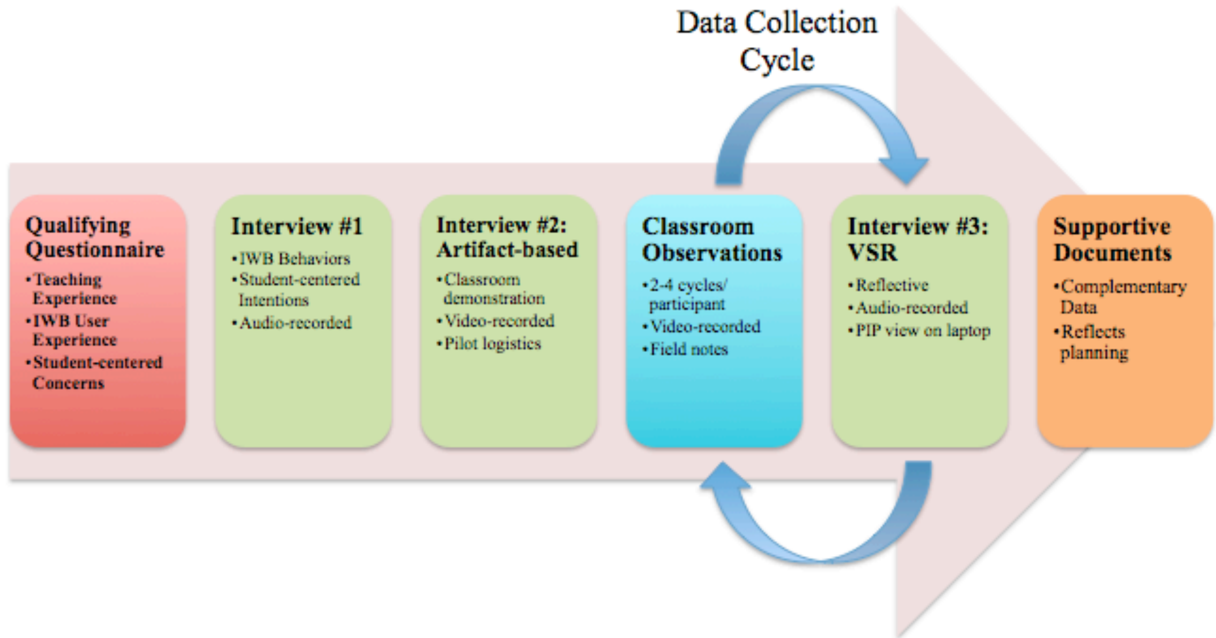

Figure 2. Overall design for participant selection and data collection.

Qualifying questionnaire. As described in a preceding section, I administered a concerns-based questionnaire to qualify participant-candidates as having student-centered intentions in their use of IWBs. In conjunction with this questionnaire, I collected basic profile information from each participant. These data included mathematics teaching experience, general history of IWB usage (checklist), IWB feature usage (checklist), and availability for multiple in-class video-recorded observations. I administered this questionnaire to all 15 participant candidates.

I used a modified version of a 35-item Stages of Concern (Hall & Hord, 2011) questionnaire originally developed to identify participants with student-based concerns using an 8-point Likert scale ranging from 0 (*irrelevant to me*) to 7 (*very true of me now*). I adapted the original survey items to refer explicitly to *the teaching of mathematics with an interactive whiteboard* in place of the original version, which limited the focal descriptive term to a single word, *innovation*. Although not encouraged by the questionnaire designers, I made some additional minor modifications on several questions to maintain sentence flow for easier reading as detailed in Appendix A. Hall and Hord (2011) promoted their original version of this questionnaire as having "strong reliability estimates (test/retest reliabilities ranging from .65 to .88) and internal consistency (alpha-coefficients range from .66 to .83)" (p. 80). I did not investigate reliability ranges for this qualitative study involving a purposeful sample of 8 participants.

Sequenced interviews. Seidman (2006) characterized the focus of his interview sequence protocol as: (1) first interview establishes context, (2) second interview allows for the construction of details within the context, and (3) third interview encourages reflection on the meaning held by the participant. For my study, the interviews paralleled Seidman's framework: (1) LoU IWB behavior-based interview, (2) mock video-recorded classroom interview without students, and (3) multiple post-video-recorded observation interviews. I developed an interview guide to ensure the systematic and consistent collection of data across all of the post-video-observation interviews. Each interview was audio recorded. By using Seidman's (2006) sequenced interview approach of three types of interviews in conjunction with a series of classroom observations and supporting documents, I developed a systematic approach to data collection that embodies Dewey's (1933) perspectives on the value of reflection, which he considered to be a meaning-making process that happens in a community. For the study, I considered the participants' communities to be their respective secondary classrooms where they used IWBs as an instructional tool to explore and interpret mathematics with their students.

Seidman (2006) recommended that each set of interviews take place within 3 to 7 days of each other. Given the rigid nature of school district calendars and the ongoing need for teachers to adjust their intended lesson pace, I made every attempt to secure interview appointments that adhered to Seidman's prescribed range. In particular, I did not launch an interview sequence if an individual data collection cycle would span a scheduled school system break.

Interview 1: Establish mathematical context interview. The goal of the first interview was twofold: (1) develop rapport with the participant, and (2) gain an understanding of how the participant planned to use an IWB in support of his or her mathematics instruction. I used Hall and Hord's (2001) behavior-based diagnostic instrument, Levels of Usage (LoU) interview protocol, to explore the various ways that teachers acted with respect to the IWB. Hall, Dirksen, and George (2008) described LoU as a classification model of "distinct states that represent observably different types of behavior and patterns of innovation use as exhibited by individuals and groups. These Levels characterize a user's development in acquiring new skills and varying use of the innovation" (p. 6).

Similar to the Stages of Concern questionnaire that I used to qualify participants, the LoU instrument provided a second qualification tool for determining placement on another CBAM classification model linking participants' behavior-based responses with their experience using an innovation. This model contains eight distinct profiles, referred to as *levels*, each representing a different approach to innovation usage. For this study design, I explored participants' planned and enacted behaviors as they related to the sixth level (LoU IVB), referred to as *refinement*. Hall et al. (2008) described this level as a "state in which the user varies the use of the innovation to increase the impact on clients within immediate sphere of influence" (p. 5). I believe this level was appropriately suited to my research focus as it reflects teachers' student-centered behavior. According to Hall et al. (2008), prior to reaching this particular LoU stage, participants are likely to self-report their actions with descriptions of learning to operate new technology or expressing interest for more training. It was my intention to secure participants who had evolved beyond learning how to access or operate basic IWB features or functionalities.

Within each LoU, Hall et al. (2008) used a scheme of seven categories to characterize the behavior type indicative of: (a) knowledge, (b) acquiring information, (c) sharing, (d) assessing, (e) planning, (f) status reporting, and (e) performing. I used a modified set of semi-structured interview probes developed by Hall et al. (2008) relevant to the refinement level. These research probes focused explicitly on exploring the participants' formal and informal evaluation of IWB usage in support of increasing student outcomes.

I modified the original interview protocol (Appendix B) in a manner that predominately adhered to the Hall et al.'s (2008) prescribed LoU design parameters. I began the second interview by confirming the participant's affirmative response to the initial decision-point question: Are you using the interactive whiteboard in your mathematics teaching? From there, I probed for a concrete example of the participant's experience by asking for a description of one lesson that included an interactive whiteboard in support of his or her lesson plan. After securing a detailed description of that lesson plan, I continued administering the suggested probes in order to further investigate the participant's rationalization of his or her IWB-based pedagogical actions.

Interview 2: Explore technology features in context. Seidman (2006) described the second interview as a researcher's opportunity to concentrate on contextualized details of the phenomenon under investigation. He recommended that the interviewer link the interview questions to an artifact. The idea is to "allow participants to reconstruct the details of their experience within the context in which it occurs" (p. 17). For this study, the artifact was the actual IWB, which included Internet access and software applications. Unlike the first interview, this one took place in the participant's classroom because the participant needed to physically demonstrate how he or she planned to use the IWB.

The protocol for the second interview was similar to the first one in that it probed *how* and *why* the participant planned to use the IWB for a specific lesson. I believe the participants could offer a more detailed description of this planned experience if they were reenacting the physical operation of the IWB. Drew (1993) described *reenactment interviewing* as

> A phenomenological method that produces meaningful descriptions . . . because the interviewer has: 1) incorporated into the interview the context of the phenomenon being explored, and 2) developed the necessary skills and techniques that put participants in touch with their feelings as well as elicit their perceptions and ideas about the phenomenon. Careful and deliberate attention to the context of a phenomenon means keeping the exploration of it grounded in experience, both the recalled experience and the present experience of the interview. (p. 347)

I designed this second interview to take the form of a demonstration where I asked each participant to show me the ways his or her class would interact with the IWB. I probed for specific examples of how the participant planned to use the IWB for upcoming lessons. My goal was to get a clear understanding of what the participant and his or her students were seeing and doing as it pertained to the IWB. I probed for how the participant connected this IWB experience to student learning. Throughout each demonstration, I explored who would be interacting with the IWB and what value the participant saw in this type of interaction. Example questions included: What is your reasoning for including an IWB to support this learning experience? How does this IWB feature influence learning mathematics? Who uses this feature in your classroom?

This second interview also served as a pilot for the technical aspects of subsequent video observations. I learned that both the lighting and sound aspects varied across each classroom setting. I also gained advanced insights into how each participant planned to travel throughout his or her classroom. For example, some participants remained in the front part of the room, whereas others routinely walked to various spots throughout the room. Because I did my own video recording, these second interviews provided me with an opportunity to pilot the technical logistics of digitally recording each participant setting. Through these pilot efforts, I made several adjustments to how I used the recording equipment and where I positioned each video camera. The pilot process also provided each participant with a chance to get familiar with wearing a wireless microphone and having a video camera tripod situated in the classroom desk arrangement.

Classroom observations. Each classroom observation served as the first part of a 2-part data collection cycle, with the complementary part being a reflective interview. I video-recorded two to four lessons for each participant. Two video cameras captured each classroom lesson. One tripod-mounted video camera remained stationary, aimed at the IWB. I personally held the second video camera in order to follow the participant as he or she moved throughout the room. Data collection from the first camera served as a record of who used the IWB and how IWB feature usage supported mathematics instruction. These data provided evidence of ways a mathematics lesson can involve sharing the IWB. I simultaneously collected complementary data from a second camera capturing participant involvement with the IWB that included audio recording sourced from a wireless microphone. In preparation for each VSR interview, I synchronized both video recordings into a single viewing screen in which the participant data was formatted as a picture-in-picture view.

Because no form of data collection provides a direct view into what the participant was thinking, I paired each classroom video-recorded observation with a follow up post-observation VSR interview. This combination of data collection methods provided me with a research avenue for exploring participants' retrospective views on *how* and *why* the IWB served as a pedagogical tool.

Interviews 3–4–5: Exploring teacher reflection on student learning. My intention for the final set of interviews was to explore the participants' reflective thoughts on how successfully they believed their implemented lesson plans supported their students' learning of mathematics. These participants' reflections provided a window into how the intended lesson plan mapped to the enacted lesson. Through an analysis of the interview responses, I learned how the participants reflected upon their IWB use to elicit student thinking.

The literature on IWB use indicated a classroom with this type of equipment as having a high level of whole-class interaction (Betcher & Lee, 2009). Because a highly interactive environment might compromise the participants' ability to recall many of the details associated with his or her recently video-recorded lessons, these interviews required a method for stimulating recollection. Calderhead (1981) promoted the use of VSR as a data collection method that lends itself to the dynamic nature of teacher-student interactions in an interactive classroom environment.

My motivation for using VSR-based interviews in conjunction with classroom observations stemmed from the concern to overcome the inherent challenge associated with gaining access to "the [participant's] capacity for direct reporting of introspective reasoning and the need to maximize the subject's use of short-term working memory" (Lyle, 2003, p. 862). When studying teachers and their actions within the classroom, Meijer, Zanting, and Verloop (2002) identified inquiry-based value derived from stimulated recall interviews through the way teachers revealed their thoughts "beyond the 'how' of teaching and into the 'why'" (p. 411). By having participants review the recently video-recorded classroom experience in an interview format, I was able to tap into their individual intentions as stimulated by the visual reenactment of IWB usage.

During these interviews, I asked participants to describe how they *had intended to use* and *actually did use* the IWB features to elicit student thinking about mathematical concepts. During this interview, I also shared a checklist of the various IWB features (Appendix C) so that the participant offered specific descriptions of IWB usage across a wide range of IWB feature options. I updated this list with additional features referenced during initial interviews.

Prior to each post-video-observation interview, I thoroughly examined each pair of video recordings for evidence of IWB usage with a focus on partitioning the data into episodes. The process of synchronizing videos warranted a significant amount of preliminary analysis to assess how best to partition each lesson into episodes. I used iMovie (2010; Version 8.0.6, Apple) video-clip tagging to delineate each episode. This process allowed me to display the entire video-recorded observation as a series of video-clip episodes so that I could facilitate the interview within whatever time constraints were present. An episode consisted of a contiguous set of interactive engagements involving IWB use by at least two classroom members (teacher with student or student with student) as they explored the mathematics. An episode began when the participant actually started using (or directed students to use) the IWB and concluded when I detected an instructional turn. These turns varied by instructional style as some participants offered a series of repetitive examples, whereas others organized their lessons into more easily definable sections.

I came to each post-video-observation interview with an episode-formatted video recording ready to view on a laptop displaying a visible counter for referencing the event's time stamp location. I was able to playback each video recording at a variety of playback speeds:

regular, 2-times, 4-times, and 8-times. This variety offered significant flexibility to the post-video-interview process, as all participants quickly became acclimated to viewing their own previous classroom instruction in fast-forward reenactment.

I launched each post-video interview with an overview of how I organized the overall classroom observation into a series of episodes. I demonstrated the fast-forward feature and stated the confidentiality aspects of these interviews. Prior to the first episode, I presented participants with a written copy of the four semi-structured interview questions:

- What type of mathematics was being explored?
- How was it being explored?
- In detail, describe the way(s) the interactive whiteboard supported your instructional goals.
- What can you tell me about how use of the interactive whiteboard related to students' learning of the mathematics?

I launched these VSR interviews by playing the first episode to its logical completion. After stopping the video, I asked the participant for the nature of the mathematics lesson. These lessons varied across secondary topics: transformations, trigonometric identities, solving special right triangles, solving systems of equations, investigating frequency distributions and histograms, analyzing polynomial equations, and exploring recursive sequences. Throughout the interview, I encouraged the participants to share in directing the flow of how we viewed the video recording. Only a few participants took the opportunity to direct me to rewind, stop, or fast-forward the video-viewing process.

I anticipated the need to model the dynamic video-viewing process. I found myself routinely asking participants if they minded if I used the fast-forward feature when no new IWB-based activity was evident. In several cases, a few of the participants asked me to rewind the recording so that we could revisit the details of a specific episode.

Supportive documents. In conjunction with the sequenced interviews and observations, I secured a copy of various documents that supported the IWB-relevant lessons. These documents included worksheets, activity descriptions, and IWB screenshots or notebook pages saved as electronic files. I used these documents as a mechanism of triangulation to either confirm patterns or illuminate inconsistencies between the participants' intentions and enactments of technology use in the mathematics classroom.

Prior (2003) explained, "The status of documents depends not so much on features intrinsic to their existence, nor on the intentions of their makers, but on factors and processes that lay beyond their boundaries" (p. 2). For this reason, each time I referenced a supplementary document during the video-stimulated interviews, I explored the participants' intentions in support of student learning. I asked the participant to assess *whether* and *how* he or she viewed these artifacts as being connected with the IWB. In some cases, the artifact served as a physical counterpart to a pre-made IWB screen display. In other cases the artifact presented evidence of a participant's lesson-planning efforts.

Data Collection Alignment with Research Questions

Anfara, Brown, and Mangione (2002) described the value of using tables when presenting research as a way "to enhance the opportunity for criticism and public inspection of qualitative studies—to encourage analytical openness" (p. 33). By mapping each method to the different research questions, I viewed the level of attention given to each question. Such a table offered transparency to the research design in addition to a means of assessing whether ample coverage of data adequately addressed the full set of research questions. Table 1 provides a mapping of each research question to its associated research methods.

Table 1

Research Questions and Data Collection Methods

Research question	Corresponding methods
How do teachers use an interactive whiteboard to elicit student thinking in a secondary mathematics classroom?	▪ Interview 2 ▪ Observations with Interviews 3–4–5 ▪ Supporting Documents
▪ Which IWB features do teachers and students use?	▪ Interview 1 ▪ Observations with Interviews 3–4–5
• How do teachers intend to use and actually use these IWB features in order to elicit student thinking?	▪ Interview 2 ▪ Observations with Interviews 3–4–5 ▪ Supporting Documents
• How do teachers elicit student thinking when students use these IWB features?	▪ Observations with Interviews 3–4–5

Pilot Studies

To ensure the data collection method provided the intended data type, I piloted the qualifying 35-item questionnaire and video recording process. Three graduate students who had experience using an IWB as an instructional tool completed the questionnaire. Their efforts provided me with example data for practicing how to use the SoC analysis tool. I also piloted the sequential interview methodology. This pilot study did not include the video-stimulated recall component. As a result of my efforts, I revised the focus of the second interview format to include a participant demonstration of the IWB. I found this revised approach to the second interview valuable, as most classroom acoustics required digital recording device adjustments.

Data Analysis

Data preparation. To analyze the prequalification questionnaire and preliminary interview I used the CBAM analysis tools to classify participants for their Stages of Concern (George, Hall, & Stiegelbauer, 2008) and Levels of Use (Hall, Dirksen, & George, 2008) profiles. For the SoC data, I translated each Likert-based questionnaire response to a CBAM template (Appendix D). I populated the SoC "Quick Scoring Device" table (Hall et al., 2008) and plotted the values on a pre-made grid illustrating each stage for "relative intensity." The questionnaire items best reflecting my study's goals aligned with the fifth SoC, consequence-stage. Example items used for this stage included these statements: *I am concerned about how teaching with the IWB affects students' learning of mathematics* (Q11) and *I would like to excite my students about learning their mathematics with an IWB* (Q24).

For the LoU data, I transcribed each audio-recorded interview. The average duration of these interviews was 34 minutes, with the shortest being 15 minutes and the longest, 60 minutes. I used the CBAM analysis tool to map the results of these highly scripted interviews with rating level guidelines provided by George et al. (2008). This process involved listening to each audio recording twice while simultaneously taking notes for evidence of LoU classification fit. The tool's authors provided example responses to assist in classifying this subjective data. For example, the participants might reference how they used the IWB to excite their students about specific concepts. In contrast, the participants representing earlier LoU stages would refer to being content with their current IWB knowledge base. I concluded this process by qualifying 8 participants as either having a high concerns-based disposition, a high behavior-based disposition, or both.

With each data collection cycle, I conducted a video-recorded classroom observation and a post-video-observation interview. Similar to the analytical benefits of personally transcribing one's own audio-recorded interviews, my video-editing efforts provided me with an immersion into the nature of each participant's IWB usage. I quickly detected the manner in which many of my participants expressed their reasoning for IWB usage as an extension of their personal teaching philosophies or styles. For the most part, the participants were highly reflective during these post-video-observation interviews.

From the 8 participants, I conducted 23 complete VSR data collection cycles, totaling approximately 28 hours of audio-recorded interview data. The shortest interview lasted 37 minutes and the longest lasted 3 hours and 15 minutes. I fully transcribed each of these interviews. When reviewing each transcript for accuracy and completeness, I conducted my initial phase of VSR interview analysis. During this process, I further refined the itemized checklist of IWB features and functionalities (Appendix C). I also used these transcription-vetting efforts to itemize a set of emergent themes on how the participants used IWB features and functionalities in support of their instruction.

Alignment with theoretical frameworks. The Cobb and Yackel (1996) emergent perspective framework emphasizes the microculture of the classroom in which sharing the mathematics takes place. Throughout the VSR process, I probed for how the participants used specific IWB features as a way of gaining insights into how the participants interpreted student thinking of the mathematics.

I analyzed the data using the two frameworks sequentially. After exploring the data for themes on the sharing aspects of the emergent perspective framework (Cobb & Yackel, 1996), I further refined my analysis to the investigation of participant usage in alignment with the

TPACK framework (Mishra & Koehler, 2006). This second framework offered a way to organize my research findings in a practical manner, as the mathematics education community frequently explores and interprets teacher education research for type of knowledge relevance: technological, pedagogical, and content.

Coding. Consistent with the two distinct but complementary frameworks noted previously, I conducted two levels of coding. I further refined my analysis of the data by applying a supplementary set of codes for the purpose of labeling evidence directly relevant to the research questions. By using computer-based qualitative research analysis software, atlas.ti (Cleverbridge, 2010), I found this multi-dimensional coding effort to be both manageable and insightful.

Level 1 coding. Using a constant comparative approach (Charmaz, 2006) to systematically explore words and phrases within the interview transcripts, I reviewed these data for evidence of how participants shared the IWB with their students to explore mathematics. By "sharing the mathematics" I mean that teachers maximize interactivity among themselves, the pupils, and the learning material as described by Miller, Glover, and Averis (2005). I identified a set of themes characterizing how participants used IWB features to visually portray the mathematics: (a) digital accentuation, (b) digital proximity, and (c) digitally enabled exploration. In each case, participants explained that certain IWB feature usage provided them with a way to share the mathematics with their students that visually honored the inherent structures of this content. By orchestrating this form of an interactive whole-class learning experience involving visual management of the mathematics, it appeared to me that the participants believed they were more likely to promote productive student thinking.

Supplementary coding. In order to interpret the data as they pertained explicitly to the research questions, I developed a set of supplementary codes. Saldana (2009) referred to this qualitative analysis technique as *structural coding*. Researchers use this form of coding to apply "a content-based or conceptual phrase representing a topic of inquiry to a segment of data that relates to a specific research question" (p. 66). For my analysis, I needed to label the data for evidence of the following relevance: (a) connections, (b) digital hub, (c) multiple representations, (d) planning for IWB use, (e) sharing the IWB use, (f) student thinking, (e) teacher philosophy/style, (f) and whole-class discussion. Each of these supplementary codes reflects some dimension of the research questions.

Connections and *multiple representations* both reflect ways teachers can view mathematical content. NCTM (2000) defined *mathematical connectedness* as mathematical ideas being interrelated across strands and grade levels. As another way of viewing the interrelatedness across mathematics, NCTM (2000) described *multiple representations* as an essential element of mathematical understanding in which a single mathematics solution has multiple modes of representation (graphical, symbolic, pictorial, or numerical). Learning mathematics involves using various representations as well as relating mathematical ideas across different representations.

Because some IWB equipment configurations integrate other digital technology, such as document cameras, spreadsheets, or third-party software applications, I labeled evidence of this integration as *digital hubbing* (Betcher & Lee, 2010). This view of the data provided me with a way to distinguish between IWB features and a particular kind of IWB functionality.

Experienced teachers plan their instruction both in advance and in real time. The interactive and dynamic nature of IWBs provides users with easy access to impromptu approaches for visually presenting mathematical content. I used this particular structural code, *planning for IWB use*, because I explicitly referenced this form of pedagogical activity in the research questions.

Consistent with my efforts to situate the findings within the emergent perspectives framework (Cobb & Yackel, 1996), I coded the data for evidence of *sharing the IWB* classroom experience. This type of evidence represented students either directly using the IWB (with or without a tablet) to communicate mathematics or indirectly using the IWB with the teacher using a *Sage-N-Scribe* (Kagan, 2013) technique. Two of the participants described using the IWB with this instructional technique in which the participant and a student share the IWB by each playing one of two roles: the sage or the scribe. For the study, participants described the student as the sage in which he or she directs the mathematical content to be written on the IWB. The participant plays the role of the scribe by writing down whatever the sage dictates. I believe these participants viewed this instructional technique as a way to incorporate students' views of the mathematics without having the students physically come to the IWB. In classrooms with 30 or more students, this instructional technique can prove logistically useful.

I found several instances of this latter scenario in which participants literally transcribed student ideas onto the IWB with no reservation about whether the mathematics was correct or complete. By using this technique, participants were in a position to see what a student perceived as correct mathematics without having to waste precious class time needed for individual students to get situated at the board. Similar to how this structural code classified the physical use of IWBs in the classroom, I also coded the data for *whole-class discussion.* My intention was to explore ways this digital equipment addressed sharing the mathematics across the classroom, not just among individuals.

Even though I designed the primary research question to investigate how teachers use the IWB to elicit student thinking, I did not explicitly ask this question of the participants. In spite of this omission, some participants discussed their views on student thinking. For that reason, I included a code for *student thinking* to capture all instances of direct reference in support of my investigation across the two primary coding frameworks.

The last structural code, *teaching philosophy/style*, was an afterthought. Early in the data collection process, I detected a pattern of the participants rationalizing their IWB-based decisions as an extension of their established pedagogical perspectives. As with any instructional tool, IWBs support teachers with the enactment of an envisioned lesson. By including this code, I more deeply explored participants' IWB use with respect to the second framework, TPACK, in which pedagogical knowledge is a primary attribute.

Level 2 coding. Once finished with coding the VSR interviews for evidence of the three IWB feature-based themes, I proceeded with a second level of coding that involved mapping the data for evidence of TPACK. As a form of thematic analysis (Boyatzis, 1998), this approach is similar to the efforts conducted by Graham, Borup, and Smith (2012), where they focused on, exploring "evidence of TPACK constructs in . . . planning and decision making, . . . obtained from candidates' open-ended responses to the request that they supply rationales for the technology they selected for the design tasks" (pp. 8–9).

In a sequential fashion, I used the TPACK framework to further classify the previously coded data. I launched this second coding effort by defining the various subcombinations of the TPACK framework: CK, TK, PK, PCK, TCK, TPK, and TPACK. Each area of teacher knowledge served as a code for situating the findings within the TPACK framework. First, I defined *mathematical content* as a multi-representational language of numerical or spatial relationships in which connected conceptual structures reflect patterns (Cuoco, Goldenberg, & Mark, 1996) involving operations, generalizations, measurements, transformations, and abstractions (Merriam-Webster.com, 2013). This definition incorporates connectedness as an inherent aspect of what mathematics means. Next, I defined *mathematical pedagogy* as a teacher decision or action pertaining to mathematical instruction involving communication, exploration, and reasoning in service of student learning (NCTM, 2000). Last, I defined *technological mathematical pedagogy* (TPACK) as technology-enabled teacher decisions or actions that influence the mathematics learning experience. In order to qualify an excerpt as having TPACK relevance, I identified evidence in the verbatim excerpt that explicitly referenced all three of the framework domains: technology (IWB), content (mathematics), and pedagogy (teaching or learning). With these definitions, I coded the data for evidence of TPACK-based instructional usage of IWB features and functionalities.

Triangulation

Research methodologists reinvented the term *triangulation* as a technique used to either validate or reveal realities in the course of analyzing data (Denzin, 1978; Fielding & Fielding, 1986; Flick, 2007). The concept of multiple realities is fundamental to the definition of triangulation. Even though researchers may have agreed upon how to use triangulation, they have sparred over the nature of its value.

I used a research design that incorporated both *methodological* and *theoretical* triangulation (Denzin, 1978). The data collection methods included survey questionnaires, structured interviews, classroom observations, video-stimulated recall interviews, and document analysis. In addition to these multiple methods, I coded each of the 23 VSR interviews for thematic patterns relevant to the two complementary frameworks.

Fielding and Fielding cautioned researchers that data situated in multiple frameworks may erroneously appear to support contradictory findings. They reconciled this misunderstanding by stating, "Theoretical triangulation does not necessarily reduce bias . . . as theories are generally the product of quite different traditions so when they are combined, one might get a fuller picture, but not a more 'objective' one" (p. 33). In alignment with this interpretation, I believe my application of two theoretical frameworks similarly reflects a way to more thoroughly explore the varied nature of how teachers use the IWB as an instructional tool. Because the present study focused on a specific technology use that served to support participants in a variety of ways, my application of different frameworks helped to illuminate deeper meaning associated with the participants' usage patterns. Moreover, the combination of theoretical frameworks does not suggest a particular view as being superior to another one; rather by situating my study within two theoretical perspectives, I offered a multifaceted perspective of the phenomenon under investigation.

Trustworthiness

Throughout the data collection and analysis processes, I deployed several research design mechanisms to establish the study's validity. I defined *validity* as "the trustworthiness of inferences drawn from data" (Eisenhart & Howe, 1992, p. 644). I included the mechanisms of triangulation, constant comparison, and peer review. Using methodological and theoretical triangulation, I explored different IWB feature usage with a diverse set of secondary mathematics concepts. I used a combination of audio-recorded interviews and video-recorded observations to corroborate participants' approaches and viewpoints representative of their IWB usage. Additionally, I provided my major professor with intermittent analytical summaries on my research progress so as to invite critical assessments of the analysis phase of this research.

By exploring my research questions through multiple methods and frameworks, I believe this study's findings carry a higher level of assurance than a similar study using a single method or framework in pursuit of obtaining trustworthy information and interpretations. This is consistent with Stake's (2006) views that "triangulation is expected to lead either to confirmation that the observation means what we think it means or to ideas about how the observation would be interpreted differently by different people" (pp. 35–36).

Upon the establishment of emergent themes and codes, I used the constant comparison process to move the analysis to higher ground. Remaining true to the mantra of systematic rigor, my use of constant comparison focused on coding at the episode level. I explored these larger chunks of data for differences and similarities. By making sequential comparisons within and across VSR interview sessions, I furthered my goal to establish analytic distinctions (Charmaz, 2006).

Finally, I used peer review with the support of my major professor as an external check of my research process. Lincoln and Guba (1985) characterized peer debriefing as an opportunity for getting a "devil's advocate" perspective. This approach holds the researcher accountable to the study by having to answer the hard questions about methods, meanings, and interpretations.

CHAPTER 4

FINDINGS

My overarching research question investigated the ways that teachers used an IWB to elicit student thinking in a secondary mathematics classroom. Throughout this section I provide evidence of how the 8 participants used IWBs emphasizing how they shared this digital device with their students. These 8 participants taught a variety of secondary mathematics courses. Table 2 provides a profile of the participants' experience levels and mathematical courses observed for this study.

Table 2

Participant Profiles

Participant	Years teaching secondary mathematics[a]	Years using IWB[a]	Course observed for VSR interview
P01	11+	6 – 10	Coordinate Algebra
P03	11 +	6 – 10	Math III (Advanced Algebra)
P05	6 – 10	6 – 10	Math II (Geometry)
P07	11 +	6 – 10	Honors Pre-Calculus/Trig
P08	11 +	3 – 5	Honors Pre-Calculus/Trig
P12	11 +	3 – 5	Extended Time Math III
P13	11 +	6 – 10	Accelerated Math I (Alg/Geometry)
P15	3 – 5	3 – 5	Math III Support

[a]Participant responses collected as range of years from preliminary questionnaire.

I organized the participants' views of their IWB usage in two ways: (1) type of digital usage, and (2) TPACK domains. I believe this approach offers a way to examine IWB usage beyond traditional technology operations such as cut-and-paste or colored highlighters. In particular, the findings offer a perspective on how IWB features could impact teachers' mathematics instruction as a shared classroom experience.

Even though all of the participants had at least 3 years of IWB experience, their individual approaches to using IWBs in support of mathematics instruction varied in terms of their placement on the three-phase developmental teaching trajectory model presented earlier. I did not anticipate how little evidence of innovative IWB feature usage (phase 3: new methods in new ways) I would find from this group of experienced participants. Specifically, I classified most of their IWB usage as either representative of the first phase (old methods in old ways) or the second phase (old methods in new ways).

The lack of observed higher-order IWB usage may have been a result of recent and multiple mathematics curricula changes. In two of the three research settings, the participants have been responsible for implementing two different mathematics curricula in the span of 5 years. This form and frequency change likely impacts teachers' abilities to focus on lesson planning that goes beyond foundational concerns of organizing instructional materials and activities. It is possible the participants did not have adequate time or resources to explore how to use IWB features as a shared classroom experience because of more pressing matters.

To illuminate how the participants' individual IWB usage varied, I organized the findings in two ways. First, I present the three digital ways participants used IWBs by describing (a) the nature of sharing to explore mathematics with their students, and (b) their placement on the trajectory model. Second, I reorganized this same set of findings in terms of teacher knowledge using the TPACK framework. Both of these approaches offer different, yet complementary, insights into how the participants used IWBs to elicit student thinking. By revisiting the data in terms of TPACK, I intended to present the findings in language more consistent with teacher education scholarship as "one of the most frequent criticisms of educational technology is that it is driven more by the imperatives of the technology than by sound pedagogical reasons" (Mishra & Koehler, 2006, p. 1004).

The first research subquestion involved the features of IWBs that teachers and students use during instruction. Rather than describing the myriad ways each feature was used, I describe the ways in which the IWB was used to teach mathematics and identify features that aligned with that use. There were three predominant ways that teachers used the IWB in mathematics instruction for: (a) digital accentuation, (b) digital proximity, and (c) digitally enabled exploration.

I found mixed results pertaining to the second research subquestion about participant engagement in instructional planning relevant to IWB use. The participants either described their planning efforts in terms of how they planned to share the IWB with an activity or whole-class discussion or did not engage in planning because their IWB usage involved spontaneous efforts to manipulate or reorganize the presentation of a mathematical representation.

The third research subquestion focused on the ways teachers share use of the IWB with students to elicit their thinking. Most of the evidence addressing that subquestion involved digitally enabled exploration. The participants tended to share the IWB with students for the purpose of problem solving by allowing students to use a few of the less sophisticated IWB features, such as colored pens and highlighting. In comparison, I believe that the participants might have been willing to share the IWB for digital accentuation or digital proximity if their students had been more familiar with how to use IWB features that went beyond colored pens and changing the background color. In spite of the limited nature of sharing, the participants said they found great value in being able to have students explore and solve problems using instant-erase features during a whole-class discussion. In general, although most participants at some point shared use of the IWB with their students in order to observe their students' mathematical thinking, those participants predominately used the IWB to operationally streamline their established instructional methods and strategies.

Digital Instruction

Throughout this study, the participants made it clear that using IWBs did not necessarily change the ways they engaged their students in whole-class discussion. Prior to having an IWB, most participants admitted to using similar instructional techniques involving dry erase colored markers and overhead projection devices to display real-time annotation. In the same breath, these participants were quick to clarify that their prior use of those techniques was less frequent and had been met with frustration. With the exception of 1 participant who boasted of having a handy tray of multi-colored chalk always within reach, most participants described their frequent frustration with dried up markers and messy overhead projector transparencies being obstacles and why they valued the IWB over the static version.

Most participants frequently described their instructional decisions in terms of dragging, shrinking, or scrolling. Specifically, they expressed value in facilitating whole-class discussion in which students witnessed the visual alteration of the mathematics. Similar to the expressed challenges of being able to use multiple colors in their instruction, the participants bemoaned the arduous efforts of writing and re-writing mathematics across multiple static whiteboards. One participant summed up the difference between non-IWB usage and IWB usage as follows:

> Before when I worked on the blackboards or [static] whiteboards or overhead, it was a lot of writing of problems and erasing it all often. Now you can just hit the button and the whole screen clears, if that's what you want to do. And it allows so much more time for interacting with [the students] rather than performing math. (P01–3 Interview, 12/12/12, Line 904)

This form of IWB usage illustrates how participants used IWBs and their predecessors, static whiteboards, in a similar fashion, but they are more efficient with IWBs. Consequently, I propose this form of IWB usage provides teachers with more opportunities to elicit student thinking than is otherwise realistic with static whiteboard instruction.

This form of IWB usage aligns with Margolin and Regev's (2011) mediation strategies used to support productive whole-class discussion. Because the IWB is a visual tool that supports whole-class instruction, this participant's comparison between instruction with and without IWBs reflects these researchers' strategy involving visual mediators to demonstrate concepts and mistakes. Although the lessons I observed did not contain drill-and-kill episodes in which students followed a step-by-step routine of producing a numerical answer, neither did these lessons present evidence of students taking an authoritative role in choosing how to explore the mathematics. For the most part, all the participants used the IWB in a way they envisioned as productive for learning mathematics that involved sharing the IWB on the teacher's terms.

Because most participants characterized their IWB usage as predominately being operationally easier as opposed to enhanced or different, the 8 experienced participants reflect the development stages of *utilization* and *integration* presented by Hooper and Rieber (1995). When considering the fourth stage of their model, *reorientation*, I believe much of my evidence depicting IWB sharing does not qualify as a form of student-centered technology adoption because any participants who had entered this stage would most likely have admitted to learning new IWB-based ways *of exploring* the mathematics from their students. Consistent with this characterization, the 8 participants described how their students appeared to know only a limited number of IWB features. In particular, the students' usage only appeared to offer presentation value, not mathematics exploration value.

Another generalized finding reflecting participants' digital instruction was their progression on the IWB trajectory model. All of the participants presented most of their IWB usage as a more efficient way of using established instructional methods in similar or new ways. This type of usage reflects the first and second phases of the trajectory model labeled *supportive didactic* and *interactive* (Miller, Glover, & Averis, 2004), respectively. Only in a few instances did I observe a participant describing his or her approach to using the IWB as one he or she considered a new method performed in a new way.

I found evidence that all of the participants used IWBs to mediate their instructional goals. In most cases, the participants enacted this mediation as an operationally easier way to conduct a lesson in which teachers, not students, led the way of how the class would use the IWB. In at least four cases, I found examples of participants who described aspects of their enacted lessons in which students took the lead using the IWB. These cases involved students using the IWB to either sort mathematical notation, label geometric figures, solve contextualized problems, or translate symbolic mathematics into mathematical drawings. A common theme across models describing technology adoption is the idea that the final stages reflect student-centered engagement. Because a prerequisite of student-centered IWB instruction is for teachers to share the IWB with their students, I explored the teachers' decisions about shared IWB usage. Using the three ways of classifying digital IWB usage, I offer evidence illuminating how I classified these 8 participants in terms of the various frameworks and models reflecting technology-based instruction that is student-centered.

Types of IWB Usage

As stated previously in the methods section of the paper, I developed a classification framework that differentiated IWB usage into 3 types: (a) digital accentuation, (b) digital proximity, and (c) digitally enabled exploration. The most prevalent among these types was the notion that the participants wanted to visually *accentuate or isolate* a portion of the mathematics during instruction. The participants expressed a need to draw student attention to a range of aspects that included, but were not limited to: (a) key concepts and connections, (b) multi-representational relationships, (c) procedural specifics, and (d) particular graphical attributes.

I identified a second type as being the participants' IWB use for the purpose of creating *digital proximity*, both near and far. In some cases, the participants wanted to promote a mathematical concept or connection by reorganizing separated visual instances of the mathematics onto a single viewing IWB screen. Consistently, I detected other evidence of participants' instructional desires involving proximity when they expressed an instructional need to display mathematics as visually connected and other mathematics as visually disconnected. Specifically, some participants saw instructional value in maintaining visual cohesion, which they addressed by presenting one version of the mathematics juxtaposition to another. In contrast, other participants expressed a need to separate remediation-level concepts as having subordinate importance. For example, several participants presented supplementary concepts on a separate digital page. In essence, the participants felt motivated to visually keep some mathematics juxtaposed and other mathematics not.

The third theme was slow to emerge. I was not quick to interpret some participants' needs to balance sharing the IWB with facilitating nonlinear whole-class problem solving. Several participants expressed recognition that authentic mathematic problem solving can be messy. Moreover, even though the ideation process of problem solving can be fluid, it typically is not an efficient use of time or workspace. Some participants associated these nonlinear solution paths with IWB workspace as easily becoming visually cluttered with extraneous work that may generate student bystander confusion. Quite often the participants expressed the need to balance their desire to welcome students who typically struggled with problem solving using the IWB with the risk of an incoherent display of mathematics left as a residue for whole-class misunderstanding. In particular, several participants used specific IWB features (shrinking, instant-erasing, and dragging) to support a *digitally enabled exploration* of mathematics because this form of IWB usage provided them with a means to offset the visual messiness of student-centered solution paths reflecting trial-and-error processes or misconceptions.

Digital accentuation. The participants demonstrated several ways they used IWB features to accentuate mathematical elements and relationships. In some cases, their use of color, highlighter, or clipart served only to automate their efforts to conduct a more visually appealing form of direct instruction. Digital accentuation served to make the presentation of the mathematics more visually stimulating. For example, when referencing her approach to teaching special right triangles with IWB color-coding and animation, 1 participant explained, “The 30-degree angle is in the same color. . . . I pop it in and out, like a little animation that [implies] . . . these two go together” (P05–1, 10/9/12, Line 479).

Upon review of the evidence in which participants stated how their IWB usage influenced student thinking, I found they used the IWB as a digital accentuation tool to: (a) train students to think like mathematicians and (b) draw student attention or focus to some point of interest. Although implementing these pedagogical strategies can promote a learning environment supportive of students thinking about the mathematics, such approaches do not necessarily influence a change in the way students think about the mathematics. Likewise, I found other evidence of digital accentuation in support of student thinking to be merely the participants’ efforts to draw students’ attention toward a particular aspect of the mathematics.

Although all the participants acknowledged that this type of IWB use was similar to its nondigital counterpart, they gave added value to its IWB-version. They used the IWB more often because of its ease of use.

Sharing the IWB. The participants who used the IWB to digitally accentuate the mathematics provided the least compelling version of sharing the IWB. For the most part, I did not observe many of the participants using the IWB to digitally accentuate the lesson content in a manner that enhanced or changed the ways they previously shared the mathematics. Consistent with this perspective, 1 participant readily admitted her concerns that sharing control of the IWB with her students undermined classroom management because some students took too long to present accurate mathematics, which generated idle time for other students to get off-task.

Although I observed some evidence of students using the IWB as a form of digital accentuation, several participants expressed interest in finding ways to facilitate lessons in which students used IWB features to emphasize their own mathematics. For instance, 1 participant said that she wanted to share the IWB with her students by asking them to use the IWB highlighter as a tracing-device. She explained that this approach would provide her with a quick and easy way to confirm students' understanding of interval notation.

Old methods in old ways. Many participants qualified their IWB usage explanations by admitting they personally favored a visual approach to learning mathematics. This preference in learning style was equally evident in their instructional styles involving the IWB. Throughout the many classroom observations, I saw participants using IWB features to visually highlight key aspects of the mathematics, visually pace students through a lesson, or visually emphasize the impact of a mathematical principle. This emphasis on visual stimulation is consistent with Ruthven and Hennessy's (2002) framework on pedagogical thinking in which they said educational technology provides a way for teachers to accentuate specific features of the content using vivid images or striking effects.

The most commonly observed approach to visually enhancing the mathematics involved using colors, highlighters, clipart, and snapshots. For the most part, all the participants used IWB colored pens to color-code a relationship or distinguish one part of the mathematics from another. In a similar fashion, they used IWB highlighter tools to draw attention to specific aspects of mathematical drawings. Because a highlighter is inherently a semi-transparent writing tool, the participants used this feature more with pictorial representations than with symbolic versions.

I observed most of the participants digitally accentuating the mathematics as a way of highlighting their own problem-solving thought processes. These participants expressed the need to model how mathematicians think. Because that thinking can be nonlinear, those participants wanted to make sure their students saw exactly which part of the mathematics they were examining and exactly how they were exploring it. In using a probing-question instructional strategy to explore trigonometric identities, 1 participant explicitly identified which elements of the mathematics supported her thinking process. She explained, "I'm training them to think [like a mathematician with] this in *their* mind as they are working. . . . I'm thinking [that] by highlighting they will remember every time, that . . . this always went in sine-squared's place" (P03–1, 10/16/12, Line 424). In this example, I believe the participant wanted to demonstrate a mathematicians' strategy to deconstruct symbolic expressions in pursuit of finding simpler and more familiar mathematical terms. Then by substituting equivalent terms (trigonometric identities) within the expressions, albeit memorized identities, the restatement of the revised expression may offer new avenues for interpreting mathematical meaning.

Old methods in new ways. Because many participants claimed an in-the-moment style of using digital accentuation, many of their explanations included evidence of using colored pens to draw attention to something on the IWB when responding to a student's question. One of the equipment manufacturers offers an IWB layer-feature that allows users to annotate any type of content projected onto the IWB screen, including PowerPoint and document camera content. One participant described the need to coordinate her spontaneous style of instruction using the annotation and the layer-features with additional efforts to design visual templates. She explained that she designed reusable templates with right triangles so her students could annotate labels on these figures as part of the problem-solving process.

Consistent with this form of IWB usage, 2 participants described their planning efforts to design lessons that used this layer-feature with worksheets or diagrams. They explained that their instructional goal was for students to use IWB features for annotating solutions on a series of related examples, which typically included the participant following behind the students' efforts with additional annotation to further emphasize particular aspects of the lesson.

Another reinvented approach to drawing student attention involved participants' usage of various IWB features to create a hide-and-reveal visual effect. Specifically, some participants used the IWB screen cover, an opaque overlay screen that slides horizontally or vertically; others used the IWB shape-maker with the drag feature to strategically hide-and-reveal content for the purpose of temporarily masking a portion of screen. These participants explained how this form of feature usage allowed them to visually partition their lecture-based instruction in order to pace students through the material minimizing confusion, distraction, or both. One participant further referenced his need for advanced planning when using hide-and-reveal because he wanted to organize, or "stage" the mathematics, when enacting his lesson.

As with many computer devices, the IWB comes with a wide array of clip art such as arrows, dotted and bold lines, and animated versions of real world items. I observed 4 participants using these IWB features to accentuate an aspect of the mathematics either by incorporating the clip art into the actual mathematical representation (as is typical with graphs) or by annotating student work samples to facilitate discussion in a particular direction. I observed a variation of this approach to using clip art for emphasis when a participant applied a visual adjustment to the mathematics in support of a lesson focused on the exploration of the rate-of-change involving exponential functions. This participant first drew an exponential function (on a IWB graph grid) and then dragged multiple vertical dashed lines across the function to represent different interval boundaries. The participant engaged the class in whole-class discussion as they watched the participant use the IWB to visually partition the function into intervals.

Because IWBs offer an easy way to selectively drag and instantly-erase visual components, this participant took advantage of the opportunity to vary the interval boundaries according to the students' suggestions. By dragging the annotated *x*-coordinate value across different intervals of the function, the participant showed the students how the average rate-of-change varied in terms of two directions of infinity. This example demonstrated technology used pedagogically to better focus students' attention on overarching ideas and processes (Ruthven & Hennessy, 2002).

New methods in new ways. Only 2 participants freely handed off control of the IWB to their students without a specific problem to be solved. I observed a participant engaging her students in two separate interactive lessons in which students used the IWB drag feature as a form of digital accentuation. In both lessons, the participant planned her instruction to include students using the IWB to emphasize mathematical relationships and notation.

In the first lesson, this participant intended for her students to explore the ambiguous case of solving triangle sides. Using dynamic geometry software, the participant designed an interactive model displaying an obtuse triangle with two legs fixed in measurement. Students used the drag feature to swing the third leg of the triangle in all directions for the purpose of identifying valid orientations and measurements that resulted in a closed geometric figure. In this lesson, the participant modeled how to drag the third leg so that the students could get a sense of how to use this visual mathematical model.

In the second lesson, this same participant used the IWB's word processing capabilities to write out seven consecutive sequence notation terms ($a_{k-3}, a_{k-2}, \ldots, a_{k+3}$), which she displayed on a blank IWB screen. She then handed off the IWB tablet to a student and told her to put the terms in order. The whole class watched the student drag the various terms into order while discussing the way this notation reflects relative position.

During the subsequent VSR interviews for these two lessons, the participant demonstrated evidence of technology adoption consistent with Hooper and Reiber's (1995) reorientation stage. The participant said that her pedagogical intention was to hand off the IWB use to her students and let them tinker (Ruthven & Hennessy, 2002) with the mathematics interactively. She described her planning process as one in which she conducted a series of informal experiments on how best to use the IWB to support student-centered learning.

Even though she admitted to fearlessly trying out IWB features in front of her students, when planning for future lessons, she routinely brainstormed ways she might use IWB features to address anticipated student misconceptions (Margolin & Regev, 2011). This unabashed attitude for learning how the IWB might support her instructional goals provided her with a strong foundation to enact her desired learning environment. This form of planning appeared to be a prerequisite for the participant's willingness to share control of the IWB with her students in a meaningful way.

Digital proximity. After conducting several VSR interviews, I became familiar with the page-based IWB features. One of the affordances of visual digital technology is its ability to virtually extend the writing page or flip to another separate digital page by merely clicking a button. Most of the participants appeared to use these forms of electronic pagination to establish digital proximity (close or distant). In particular, they chose either to display one form of mathematics juxtaposed to another or to physically separate those forms by dragging or cloning the digital objects to a different digital page.

Sharing the IWB. Throughout the study, I never witnessed a student using the IWB for digital proximity. Only in one VSR interview did I find evidence of a participant who said his student had asked him to reorganize a problem solution so that all of its parts were displayed on a single IWB page.

The participants offered mixed views on how they felt about sharing the IWB with their students. For the most part, all of the participants saw educative value in having students use the IWB features. The primary reservation offered by 3 participants involved classroom management issues. One participant explained that she used the page-scrolling feature because it helped her to maintain a continuous flow of instruction. One of her instructional goals was to keep the pace consistently moving with little to no down time in fear that some of her students would abuse any break in the flow as an opportunity to go off-task.

When describing her shared use involving digital proximity, 1 participant said that she was able to offer more students increased opportunities to present their mathematics because she was no longer rewriting mathematics problems in response to students' delayed questions. Her claim relied strictly on class time efficiencies gained from being able to conveniently click a button and instantly scroll or page back as needed. I believe this benefit of time efficiency translates into more student use of the IWB, which qualifies as an indirect influence reflecting Heid's (1997) synergistic principles for student-centered technology-based learning.

Old methods in old ways. Several participants explained that they used IWB features to visually present multiple representations of the same mathematical expression. The common instructional goal was to display both representations on the same page to serve as a visual trigger for students to think about the relationship between the two versions of mathematics. For example, when exploring the procedures associated with using the rational zero test for solving rational functions, 1 participant explained, "If I were to have [the list of possible rational zeros] on a different [digital] page, and then I were to draw my *x*-*y* axes and then plot those zeros right there, some kids [might not] tune into that" (P12–1, 10/23/12, Line 142). This evidence suggests that if participants used IWB features to relocate the symbolic values in the same viewing screen as its graphical representation counterpart, then their students were more likely to draw visual conclusions involving interrelatedness.

Old methods in new ways. Five participants cited instruction focused on mathematical connections and multiple representations as the most common benefit realized from their IWB use involving digital proximity. Among the several mathematical concepts referenced, those participants were quick to describe how they used a variety of IWB features to visually present interrelated mathematics on the same digital page. One participant explained, "I put it up so they could see that the transformations are going to be the same regardless of what the function looks like" (P01–1, 11/8/12, Line 46). Another participant stated,

> I want this to stay in front of them. I don't want this to go to another [IWB] page. I'm going to step over here and we're going to talk about it and I'm going to add some things

> to it. But I don't want [students] to lose sight of that because I'm trying to tie all this together. (P01–1, 11/8/12, Line 56)

All the participants referenced specific IWB features when they intended to create digital proximity in support of visually displaying connectedness or multiple representations. These features included: split-screen, cut-and-paste, cloning, and shrink/enlarge. Each of these IWB features offers a way to take an existing visual display of mathematics, in any form (symbolic, graphical, drawings), and move or copy it to another IWB page or different part of the IWB viewing screen. The size or orientation can also be changed if so desired.

One example of this instructional strategy involved spontaneously offering students a dual-view (elimination versus substitution) of how to use different approaches for solving systems of equations. Several participants described a previous experience in which a student changed his or her mind on a single preferred solution method that was later countered by another student wanting to see the other approach. In this scenario, the participants used the IWB features to create a single viewing area displaying both solution approaches. Even though several participants referenced this specific example, they did not use the same IWB features to accomplish the same goal. In fact, only 1 participant used the split-screen feature. When I asked others if they would consider using this particular IWB feature, they said they might if they knew more about it.

Referencing the same lesson topic, another participant described her desire to present the mathematics in a way that students could compare and contrast the two different approaches to solving a system of equations. She explained that the instructional benefit was to be able to spontaneously respond to a student question on an alternative approach and say,

> Let's work it using the other method. So I paged it back, shrunk it up, moved it over to the left. . . . They had substitution over here, elimination over here, and . . . we came up with the same solution. (P01–3, 12/11/12, Line 470)

Several of the participants also described their usage of the extend-page feature as an application of digital proximity. This IWB feature provides a way to maintain visual flow when solving lengthy mathematics problems. Interview discussions typically included participants reminiscing about the days when they would either roll their overhead transparencies through multiple "messy" screens or completely fill multiple panels of their classroom static whiteboards. In fact, 2 participants appeared regretful when admitting to erasing parts of a mathematics solution on an overhead projector prior to completing a solution because they needed more room to finish writing.

New method in new way. A common occurrence involving whole-class discussion dealt with how students referenced the IWB when asking questions. At least 2 participants noticed that their students were less reluctant to ask questions in comparison to non-IWB instruction. Specifically, they stated that their students appeared less apprehensive to ask the participant to go back to the written work on a previous problem. These participants explained that the scrolling back process was no longer viewed as an inconvenience. In particular, 1 participant described this IWB influence as one where students "have a comfort level of knowing, that if I needed to, I could go back. If they needed to, they could go back. If they're not able to keep up, they know that it's still there" (P03–1, 10/16/12, Line 1095). In essence, by having access to digital proximity features, whole-class discussion appears more likely to follow a path reflecting students' thinking paths than without this type of IWB usage. In a simplistic form, the teacher shares the decision of whether or not to return to a previous problem for clarification. Reflecting a synergistic principle characterizing student-centered technology usage in the mathematics classroom (Heid, 1997), students may not have an equal share in determining the problem-solving path, but this IWB features affords them at least some authority in the exploration process.

When discussing how IWB features supported their efforts for productive whole-class discussion, 4 participants emphasized how beneficial the digital proximity was to their instruction when they needed to keep some mathematics visually separated. For example, if a student asked a question that a participant thought raised the potential to confuse or derail whole-class discussion, the participant used the IWB new-page feature to separate this content. Moreover, the participant struggled with the trade-off of wanting to respond to a student's questions by visually presenting mathematics and posting content she considered confusing or conflicting with the current lesson's topic. She resolved the challenge by providing an answer on a separate digital page and then quickly and neatly navigating away from that page when finished. I believe this example illustrates how teachers can feel more empowered to support more of their students' questions and suggestions on how to explore the mathematics that are consistent with many of the student-centered frameworks involving technology adoption (Hall & Hord, 2011; Heid, 1997; Hooper & Reiber, 1995; Margolin & Regev, 2011)

Digitally enabled exploration. As a third type of IWB usage, I observed 4 participants using IWB features to support mathematics instruction that involved student-centered exploration of problem solving as a whole-class discussion. I propose student-centered instruction does not mandate that the student is the one actually writing on the IWB; rather, the participants described IWB usage in two forms. The first form involved students writing on the IWB. The second form involved participants transcribing their students' thought as they dictated them. Digitally enabled exploration involves the enactment of *students*' ideas on how to solve a problem. The motivation for identifying this form of IWB usage stemmed from my observation that 2 participants expressed reluctance to hand over control of the IWB to their students. In particular, those participants referenced concerns for introducing time inefficiencies or promoting mathematical misconceptions during whole-class discussion. Three other participants appeased their concerns with the support of the undo feature (back-button or instant-erase) or by selectively erasing content using the layer-feature.

Sharing the IWB. Because the IWB can function as a digital hub for other presentation equipment such as document cameras, 2 participants described lesson components in which they displayed student homework samples on the IWB screen. Using the IWB layer-feature, the students either used a digital pointer or annotation to present their work. This form of sharing the IWB was not as prevalent as those in which students wrote directly on an IWB page.

When discussing how they digitally explored mathematics as a whole-class discussion, 6 participants praised the way IWBs enabled users to instantly and selectively erase mathematics perceived as problematic. In fact, 1 participant admitted to minimizing student involvement with problem solving if she considered the student to have weak mathematics skills. The participants' fears stemmed from concerns that these students' efforts would derail their instructional goals.

Old methods in old ways. When using the IWB for exploration-based instruction, 2 participants emphasized how using the point-and-click nature of IWB features aligned with their conversational styles of teaching. It appeared that these participants believed the IWB provided them with greater flexibility to engage their students in whole-class discussions than they realized when using a static whiteboard. They explained that those features allowed them to more easily manage classroom discourse while still tending to the quality of students' shared content on the IWB.

Students sharing mathematics in conversational classroom discourse can involve whole-class discussions that do not always lead to a solution. One participant described her conversational mode of instruction as a free-flowing discourse of mathematical ideas in which students “don’t hesitate to ask [questions]. We can scroll back up . . . to another problem” (P03–1, 10/16/12, Line 204). Three participants also referenced pedagogical benefits such as time efficiencies realized by not having to constantly erase problematic attempts at student-authored mathematical solutions.

One participant rationalized her preference for using an IWB during whole-class exploration of mathematics as a way of avoiding the messiness associated with non-IWB student-centered problem solving. She described the equivalent static whiteboard experiences as ones in which students might draw a graph, trace parts of a graph in error, attempt to erase a single part of a graph, and find themselves erasing more than they intended in such a way that several other students ended up confused. In contrast, the same student could make similar mistakes and use IWB features in a way that was far more forgiving “because [the student] can go back and undo, touch-up, and [continue with] whatever [the student] has to do” (P12–1, 10/23/12, Line 908). In essence, this form of IWB use replicated what 3 participants did in the past, but now it involved less time and less mess. Such a form of IWB usage represents an example of how some participants used technology to teach mathematics using an instructional method that embraced student-centered learning, which was one of Heid’s (1997) synergistic principles on pedagogical value.

Old methods in new ways. In addition to students using the IWB undo feature to instantly erase parts of their problem-solving efforts, 2 participants also used that feature when working in a sage-and-scribe mode. This mode of student-centered problem solving involved participants writing on the IWB exactly what students described during whole-class discussion regardless of whether the student's mathematics was correct or not. One participant explained that the benefit of having students' mathematics posted on the IWB was that

> a lot of times it opens up things that they didn't see when they were sitting there alone. So I like. . . [to] take out all of the factors that keep [students] from being successful doing [the mathematics], and I like the idea of them actively participating and thinking out loud. (P03–1, 10/16/12, Line 122)

Five participants described using the IWB for digitally exploring mathematics as student-centered, spontaneous, and easier to facilitate. Because using IWB features to digitally enable the exploration of mathematics is a way of investigating in the moment, the participants did not necessarily engage in planning efforts prior to using this form of instructional technology. In one VSR interview, a participant explained how she routinely used the undo feature to record students' nonlinear thought processes by transcribing exactly what the students said. She described this process saying, "You have to use your class and you have to judge your class in the moment, . . . that it's an in-the-moment thing" (P05–3, 11/8/12, Line 678).

These findings suggest that many participants did not engage in instructional planning for this type of IWB usage, because it was predominately a reactionary strategy used to engage students in whole-class discussions enacted in real time. For example, 1 participant described looking at her students' faces and deciding that she needed to find another way to present the mathematics. She detailed this account stating:

> Let me back up. Let me go again and let me try to be more concrete. Or let me just show you a different way. And what can I use that the [interactive white] board has available that will help me do that? Help me to help you to understand this. (P01–3, 11/29/12, Line 282).

This evidence portrays the real time nature of participants' IWB usage associated with digitally enabled explorations.

Although 5 participants described their efforts as reactionary, 3 of those participants explained that when an IWB-based in-the-moment usage proved successful, they would eventually revisit that pedagogical strategy as a topic for planning consideration. In essence, sometimes participants unexpectedly uncovered in-the-moment IWB approaches to digitally enabled explorations and later made them the focus of future planning efforts.

During nine classroom observations, I observed students solving problems in the presence of their peers in which they displayed a written record of their thought processes. Because the IWB is a whole-class instructional tool viewable by all students, the entire class is in a position to witness, and thus question, how another student solved a problem. This form of learning reflects the sociocultural learning environment presented by Cobb and Yackel (1996) when they described students sharing mathematics. One participant described this form of classroom learning when she explained that students used the IWB to "express the communication that's going on inside their head" (P05–2, 10/18/12, Line 146), which enabled a friendly mode of exploring mathematics in a communal classroom environment. This same participant further explained that when students solved a problem using a geometric diagram, she watched her student size up the problem. She clarified, "It's not that I'm looking at work that's already finished. . . . I can see it, every step of their thinking process. What they remember, what vocabulary they remember, how much detail they'll put on their pictures" (P05–1, 10/9/12, Line 157).

This form of digitally enabled exploration provided fuel for more whole-class discussion because when students felt less intimidated to ask questions, more discussion took place. With more student inquiry, participants more frequently were in a position to detect or elicit students' thinking.

New methods in new ways. I did not observe any of the participants using the IWB to digitally explore mathematics in a manner that I considered completely new. I speculate that one such instructional approach would involve interactive or dynamic software applications or multimedia that supports the simultaneous visual exploration of mathematics. I also believe these new methods would involve visual versions of mathematics that are linked in such a matter that students can explore the interrelatedness of mathematics without the need for teachers to intervene in reorganizing the presentation of the mathematics.

TPACK Classification

When exploring how teachers use IWBs, the extant literature offers a teaching trajectory model in addition to a detailed classification of the various IWB features. My initial analysis of the data resulted in the identification of specific IWB feature usage and the development of an approach for classifying how participants used these features during instruction. Both of these results provided a technology-centered view of IWB usage.

Mishra and Koehler (2006) promote their TPACK framework as having two values. The first "allows us to critique simplistic approaches toward developing teacher knowledge. . . . [Second, it] helps us in conducting scholarship and research into the nature and development of teacher knowledge" (p. 1045). Moreover, they promote the usefulness of their analytic framework as a way to examine and to classify teacher decisions relevant to instructional technology and subject matter in authentic contexts.

By further presenting the findings through the classification lens of the multiple types of teacher TPACK knowledge, I offer a view of the participants' IWB usage intentions, varying from simple to complex. For example, 3 participants saw pedagogical value strictly in terms of time efficiency, whereas 4 participants explained their IWB usage supported their intention to have students demonstrate a specific mathematical relationship. Although both pedagogical values have merit, the second one links pedagogy with mathematical content as a means of eliciting students' mathematical thinking.

Because this study focused specifically on participants' usage of IWBs, a form of instructional technology, I limited my TPACK classification to those categories in which technology is relevant: technological knowledge (TK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical and content knowledge (TPACK).

I conducted this classification process by initially defining mathematics content and mathematics pedagogy consistent with NCTM's (2000) standards and principles. I provided detailed definitions for these terms in the prior section with other coding definitions. Because teaching mathematics involves its own set of standards and principles (NCTM, 2000), I believe this TPACK classification process is useful in that it extends the existing body of research on educational technology to include an identification of how IWB usage aligns with teacher knowledge specific to mathematics education. I did not find evidence of all three types of IWB usage relevant to each TPACK knowledge domain combination.

Technological knowledge. I purposefully selected this study's sample to include participants with foundational expertise and familiarity in using IWBs. During the initial interviews, 7 participants explained that they used only a small fraction of the IWB features. The 8 participants completed the initial questionnaire profile stating that they learned how to use the IWB through a combination of sources: workshops, self-taught, and collaborative peer groups. In one instance, a participant also checked off the college coursework option. None of the participants responded positively to learning through: online tutorial, vendor seminar, or other.

In classrooms where participants shared the IWB with their students, the participants' technical expertise appeared to influence the level and nature of this sharing. Even though participants took advantage of various IWB training opportunities, no such options existed for students. For the most part, the participants explained that students' IWB expertise resulted from either watching various teachers use the IWB over the course of multiple years, as all participants stated their middle school counterparts also used IWBs, or students personally using the IWB before, during, or after class. Because students had limited opportunities to explore the available IWB features, I observed most of the students' usage as accessing colored pens, eraser, undo (instant-erase), and free-hand drawing. In three observations, I observed students using the colored highlighter and line/shape-maker tools for graphing.

All the participants' IWB usage favored applying visual emphasis on some part of their mathematics instruction. These participants demonstrated knowledge of how to use digital paging features (extend, new, scroll up and down) during at least one lesson. When discussing this type of feature usage, 1 participant described a digital norm that she had established with her students. This norm involved the students' expectation "that when [the participant] paged to the next page, you're done" (P03–3, DATE, Line 332) discussing the current topic. This participant used the paging feature to signal that she had finished with one problem or concept and was beginning something new. When used as a digital exploration tool, 2 participants limited this form of use to the IWB undo (instant-erase) feature.

Technological content knowledge. When participants explained how they used a particular IWB feature, they infrequently referenced their usage exclusively in terms of the structure of mathematics. In contrast, when they talked about using IWB features in reference to mathematics, the participants emphasized the pedagogical benefits associated with their IWB feature usage.

One participant's comfort with technology far outweighed that of the other seven. He routinely described how he was either reading about or experimenting with a new instructional technology with an eye on how it might offer a better way to investigate various mathematical concepts. For example, he downloaded an application enabling the use of his iPad mini as a wireless tablet in conjunction with the IWB. The configuration allowed him to integrate some type of IWB scribing feature with his students' laptops. He stressed how he valued the IWB dragging feature stating, "These [polynomial graphs] are algebraic objects that can be manipulated [on the IWB], which plays right into the heart of transformations. If this is an object, it can be manipulated" (P08–1, 10/9/12, Line 799).

Technological pedagogical knowledge. In contrast to the minimal evidence I found relevant to IWB-based mathematical content knowledge, the participants frequently indicated that they used IWB features to support pedagogical strategies that did not necessarily apply exclusively to mathematics. Seven participants described the ease and flexibility the IWB offered them when their goal involved emphasizing a particular aspect of written instruction. This emphasis typically took the form of using the IWB colored pens or highlighters. In one case, a participant referenced how the IWB features offered pedagogical value because she conducted her lessons with less down time. She characterized this value stating, "Simple for me, more engaging [and] . . . focused for them" (P12–1, 10/23/12, Line 658).

TPK of digital accentuation. Participants often described their instructional goals in terms of needing to accentuate an aspect of the lesson. For instance, some participants explained their intentions as being centered on maintaining students' interests by stating, "I just think different people learn different ways and it just gives a different look to what we're doing and I think it adds some depth to what is going on there so they can, hopefully, see it better" (P01–1, 11/8/12, Line 126). Although this participant may have had a mathematical concept in mind, her explanation made no reference to it. Similarly, 3 participants expressed a pedagogical need to minimize the possibility of overwhelming their students with too much content or a need to color-coordinate different parts of the content.

Five participants drew connections between their use of IWB features and their ability to influence how students think about the lesson content. An example I encountered involved a participant's description of how the clone-feature provided an instructional tool "to accentuate the point that what I'm about to do is very similar to what I just did. I'm repeating something but I'm then going to add onto it" (P07–1, 10/31/12, Line 204). This participant believed this form of IWB usage shaped student thinking because if the participant had merely rewritten the content, the students would "feel like it's a totally different step but, in fact, it really isn't" (P07–1, 10/31/12, Line 226).

Another example I observed pertained to the hide-and-reveal feature. When using this IWB-based instructional technique, 1 participant described how she considered organizing content in a manner where specific parts were temporarily hidden. She envisioned this instructional strategy, explaining, "If I were to hide it, but then they're going to have to ask, 'Why are you hiding this?'" (P12–1, 10/23/12, Line 284). She further proposed that using the IWB hide-and-reveal feature "would definitely get [the students] asking questions. And get them thinking" (P12–1, 10/23/12, Line 302). Although this participant did not actually engage in this type of IWB usage, I believe she considered hiding mathematical content as a way of prompting students' attention. By selectively hiding some of the lecture content during instruction, she would encourage her students to want to know why.

TPK of digital proximity. As described earlier, the participants used digital proximity to visually situate one part of a lesson's content juxtaposed or separated from another part. When observing their video-recorded lessons, participants stated that they used certain IWB features to visually influence how the students viewed relationships across a lesson's content. Although this study focused exclusively on secondary mathematics content, the participants rationalized some of their instructional decisions with generalized pedagogical reasoning. For example, they claimed to be using the IWB page features to create a visual boundary or progression on how to interpret the lesson with no regard to the particular content.

One participant described how she used the scroll feature to keep a section of a lesson's content on a single digital page so that she could manage her own instructional efforts, stating, "Everything being one line below the previous is, it just cleans up teaching" (P03–1, 10/16/12, Line 1131). Another participant described how she used the IWB shrink and cut-and-paste features to reorganize different parts of a lesson's content so that they displayed on a single digital page. She explained,

> We're kind of done talking about it directly, but indirectly we're going to use that. We're going to expound on it. We're going to apply it to something that's coming up and so, kind of subliminally I think if it's still there . . . it's still going to be in front of [the students] and [they are] still going to be thinking of it. (P01–3, 11/29/12, Line 56)

Three participants viewed using IWBs for the purpose of creating digital proximity as a tool for lowering student distraction. In particular, those participants expressed the need to manage the amount of content and pace of their lessons. They described how their IWB usage served these pedagogical goals by visually reorganizing lesson content so that students saw content juxtaposition. One participant explained her pedagogical reasoning for this approach:

"Unless [students] see it, it doesn't matter. . . . I just think a picture is worth a thousand words. I can convince [them] if [they] can see it side-by-side up there" (P01–1, 11/8/12, Line 393). Furthermore, another participant recalled his students asking him to reorganize content so that it was presented on the same IWB page. He reasoned that this form of IWB usage helped students "if they have trouble remembering what we just did or if they need to copy something from the last question" (P15–1, 12/3/12, Line 332).

TPK of digitally enabled exploration. Throughout the VSR interviews, the participants frequently referenced the value of using IWB features to maintain the flow and focus of their intended lessons. Using the undo (instant-erase) and toggle features, the participants expressed their ability to support student-centered approaches to exploring a lesson's content with ease and flexibility. Additionally, 5 participants referenced having greater control of time management in terms of offering more repetition during whole-class discussion without the need to actually rewrite the mathematics.

The participants' concerns for balancing the time management challenges of facilitating student-centered lessons while not sacrificing content coverage were consistently evident in the data. One participant summed up this viewpoint by stating, "You can get it up there quickly and you can get it off quickly. We're moving on" (P01–1, 11/8/12, Line 214). Not only did participants value the ease of instantly and neatly reversing any IWB content, they enjoyed the flexibility of using IWB features in the moment. As one explained, "If I need to call up something from the Internet, I can have it open at the bottom [using the toggle-feature]. If I have a PowerPoint I need to use, or two or three [other resources], I can call [these] up at the bottom" (P05–2, 10/18/12, Line 552). Moreover, this participant saw that form of IWB usage as a way to support student-centered instruction in spite of the unpredictable nature of her classroom dynamic.

TPACK. Throughout the data collection process, I uncovered a variety of ways participants used IWB features to engage their students in learning mathematics. In some cases, 3 participants readily acknowledged their intentions to use this technology a certain way for a certain instructional purpose. In other cases, 4 participants expressed reflective thoughts on how they envisioned using this instructional tool in support of engaging students in sharing mathematics as a whole-class learning experience.

I observed 3 participants inviting students to the IWB to solve contextualized mathematics problems. These problems included special right triangles for angles of depression, trigonometry for shadow lengths, and arc and circle length for bike tire dimension calculations. A common theme identified among the TPACK relevant evidence was that the participants used IWB features for collaborative problem solving. "Problem solving is an integral part of all mathematics learning" (NCTM, 2000, p. 52). Depending on the nature of their IWB usage, the participants enacted lessons involving problem solving either to model it, to explore reasoning in support of it, or to share authority in conducting it. By using IWB features for problem solving, the participants engaged their students visually and interactively in the application of mathematics to real world contexts.

TPACK of Digital Accentuation. I found evidence suggesting that almost all of the observed lessons reflected TPACK in a way that involved digital accentuation focused on either modeling problem solving or mathematical notation as a whole-class learning experience. Some participants favored using IWB colored pens or highlighter, whereas others limited their IWB feature usage to dragging objects or symbols across the digital page. The lesson topics included a variety of mathematical concepts and conventions, which included but were not limited to transformations, trigonometric identities, recursive sequence notation, and special right triangles.

One participant described her previous frustration with helping her students truly appreciate the conceptual understanding of what it means to have an ambiguous case for solving the side lengths of an obtuse triangle. Her instructional goal for the lesson was one in which students engaged in the exploration of this topic:

> I just know how complicated it is. It's pretty difficult for them to see the [configuration]. . . . But for them to actually see what's happening, and the sides [dynamically] changing and how long it has to be. . . . It works so much better when they can manipulate [the mathematics], or they can see it being manipulated. . . . Things can be moved, angles can be changed, links can be changed, and every time you move something, its label stays with it. So opposite stays opposite, and adjacent stays adjacent, and so it just makes it so much easier for them to visualize—for them to actually see what is going on. (P03–2, 11/8/12, Line 72)

In this example, the participant designed an interactive model of the ambiguous case using dynamic geometry software, which she projected on the IWB. She handed off the IWB wireless tablet to a student for him to manipulate the model. Although this participant typically claimed she preferred not to hand off the tablet to students, she believed the drag feature was intuitive enough for the student to easily explore the mathematics in a whole-class learning experience. This example provides evidence of this participant's TPACK because she designed her lesson using technology to engage her students in an interactive exploration of a dynamic mathematics concept that would look different without the IWB.

When exploring interval notation, another participant described her planning efforts, which included choosing which parts of the mathematics to isolate so that she could visually and verbally highlight their individual contributions to solving the problem. This participant used the IWB to draw a function freehand on a coordinate grid. Then she used the IWB highlighter and line-maker features to visually emphasize the *x*-axis between two points. She explained,

> My goal in doing this is I wanted to divide the function up with those vertical lines to say, "Okay we're looking at this portion of the domain." And [the students] could tell me by looking at the graph between that, in that interval, which one was growing more rapidly. . . . "What if I just tell you I'm in these intervals of *x*'s? Can you still do it for me?" And I was very pleased that they could. (P01–1, 11/8/12, Line 641)

Similarly, another participant described her efforts to facilitate whole-class discussion focused on solving special right triangles:

> [I] highlight or move a segment or take something out of a picture and look at it as an isolated piece. Especially for someone who struggles to identify distance in a picture, [I find it helpful] that we can really highlight that and kind of remove it from the whole. It helps to bring [students'] focus into what's important in the problem and to take away their focus from the things in the problem [solving process] that are not going to help them or not be important. (P05–2, 10/18/12, Line 328)

Once again, the participants' IWB usage provided evidence of their TPACK. By modeling mathematics problem solving using the IWB technology, both of these participants described how they engaged their students in whole-class discussion that served their pedagogical intentions.

TPACK of Digital Proximity. I found evidence suggesting that some of the participants used TPACK when they described their pedagogical decisions to use IWB paging features as an instructional strategy for visually encouraging their students to focus on the reasoning behind a mathematical relationship. These participants described how they used the IWB to organize the visual presentation of a problem's solution in which they displayed different parts as either juxtaposed or separated from each other.

When exploring the various ways to analyze rational functions, 1 participant recalled the challenges his students routinely faced with the significant number of components involved in this area of mathematical analysis. As a self-proclaimed visual learner, he felt compelled to use IWB features in a way that grouped aspects of this lesson onto a single extended viewing space. Specifically, this participant described how he used the IWB scrolling feature to visually emphasize connections between specific characteristics of a rational function's graph and the symbolic versions of these characteristics. During the post-observation interview, he shared his recollection of wanting to separate the lesson content because students from prior years had demonstrated a better grasp of the whole function if he separated the parts. In an effort to unpack the individual function characteristics and their graphical relationships, the participant exhibited his TPACK because he described his lesson-planning efforts in terms of helping students make mathematics connections using the IWB paging features. He explained,

> I purposely wanted to keep that all together. And I think physically having it all on the same [IWB] screen solidifies that connection that I want them to have as opposed to putting the graph on a different page from the characteristics. To me, I [need to] see it [together]; [otherwise], there's a little bit of a disconnect. It is a lot easier to go back and forth, you know to connect the characteristics with the graph as you're graphing it. . . . Because especially with rational functions, there are different parts. . . . I have found over the years that it's a lot easier for the kids to grasp the whole function, if I break it down into parts. (P07–3, 11/28/12, Line 331)

This example illustrates how he used an IWB feature to serve his sense of student learning challenges with a specific mathematics concept.

TPACK of Digitally Enabled Exploration. Upon review of the evidence pairing the digitally enabled exploration form of IWB usage with the TPACK classification of teacher knowledge, I found the participants demonstrated more alignment with Cobb and Yackel's (1996) emergent perspective framework than with either of the other two forms of IWB usage. Evidence in support of this form of IWB usage involved students using the IWB in a meaningful way. Some participants described the instructional advantage of this form of IWB usage as a way for them to share the IWB regardless of whether the students' problem-solving efforts reflected flawed mathematical reasoning. Another factor may have been the participants' views of students as competent users of the undo and instant-erase features.

A few participants demonstrated little to no evidence of sharing authority of the IWB for exploring mathematics; either the students used the IWB in a highly structured way or not at all. The participants' explanations for minimizing sharing appeared to reflect TPACK because this instructional choice involved consideration of the negative impact student IWB use might have on their ability to facilitate a productive whole-class lesson. In particular, those participants expressed concern for handing over control of the IWB to their students in terms of time efficiency, messy problem-solving paths, and publicly shared misconceptions.

Consistent with this form of digitally enabled exploration, I found evidence in support of participants using TPACK with an IWB in a lesson focused on solving trigonometric identities. In this example in which the students had an active role in exploring the mathematics, the participant rationalized her lesson approach as a nonlinear problem-solving process where students

> make mistakes and erase and change and discuss [a problem solution]. So often [students] will ask questions and they didn't get past the second step because they . . . didn't want to think about it any more than that and they got stuck and they quit. And when they're writing and we're discussing, a lot of times it opens up things that they didn't see when they were sitting there alone. I take out all of the factors that keeps them from being successful. . . . I like the idea of them actively participating and thinking out loud. (P03–1, 10/16/12, Line 122)

In this example, the participant anticipated the frustration that some students experienced in exploring problems of this nature. Because the participant embraced a conversational mode of instruction, she frequently posed what-if questions. This conversational mode of conjecture works well with the IWB undo feature because whole-class discussion may go down a number of problem-solving paths that do not result in a solution. I classified this participant's IWB use as a demonstration of TPACK because it involved student-centered instruction in which multiple students explored and discussed how and why they solved problems.

By examining the finding with these two classification models, I offer a way of viewing the participants' IWB usage that illuminates pedagogical decisions relevant to mathematics instruction. This approach provides the reader with a view of a technological tool usage that emphasizes teachers' instructional intentions, rather than the tool's operational capability.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Consistent with Peressini and Knuth's (2005) promotion of teachers needing to "develop, practice, and implement new forms of instruction . . . that are grounded in the meaningful use of technology" (p. 277), this study examined how eight experienced secondary mathematics teachers used IWBs to support their instruction. In particular, I explored how these participants used IWBs to elicit student thinking with the support of an IWB. Sharing the use of IWB features to present a visual version of mathematics does not reflect meaningful use of educational technology. In order for IWB-based instruction to offer pedagogical value beyond operationally simplifying established or new methods, teachers need to encourage students to use IWB features that go beyond different colored pens and backgrounds. The current body of research on IWB usage focuses on itemizing lists of IWB features and the nature of how teachers' instructional IWB usage evolves over time. Unfortunately what these two constructs look like in a secondary mathematics classroom remains obscure.

Summary

Because mathematics education has its own set of guiding principles and standards (NCTM, 2000), I situated this study within two frameworks that view mathematics content as having specific teaching attributes. First, I explored my data from the perspective that an IWB is a type of whole-class educational technology in which both teachers and students share its features when exploring mathematics. This is consistent with Cobb and Yackel's (1996) emergent perspective framework promoting the learning of mathematics as a sociocultural process. I believe my study serves as an application of this framework in that the 8 participants viewed their IWB-based instruction as a whole-class learning experience where sharing takes place.

My research intention was to frame my findings in a manner that extends beyond IWB usage. To accomplish that, I chose to reconsider these findings in a way that translates digital technology usage into teacher decisions. As a doctoral student interested in research scholarship that integrates educational technology with mathematics education, I see value in taking these findings to another level. For that reason, I chose a second framework: Mishra and Koehler's (2006) TPACK framework. Because that framework delineates the various combinations of teacher knowledge domains (technological, pedagogical, and content), I used the framework's language to classify and interpret the wide array of participants' perspectives. By viewing my data through the TPACK framework, I explored how the participants "emphasized the connections, interactions, affordances, and constraints between and among content, pedagogy, and technology" (p. 1025). This framework offered a way for me to investigate the complex interplay associated with participants' decisions on how they think about the IWB as an instructional tool to support the elicitation of student thinking.

I designed the methodology for this study as a two-phase process: (1) prequalification of participants based on IWB experience and extent to which they engaged in student-centered instruction and (2) multiple data collection cycles of observations followed by video-stimulated recall interviews. For the prequalification process, I adapted Hall and Hord's (2011) questionnaire and interview protocols to classify participants who represented mature usage of IWBs. Both of these instruments reflect Fuller's (1969) concerns-based adoption model in which teachers' concerns and behavior are viewed from the perspective of their adoption of an innovative technology. The second phase involved a series of video-recorded classroom observations, each followed by a VSR interview. I also collected copies of participants' planning documents as evidence of intentional IWB usage.

Using open coding, I systematically identified themes across the post-video-observation interview data reflecting three types of IWB feature usage: (a) digital accentuation, (b) digital proximity, and (c) digitally enabled exploration. Next, I systematically classified the previously coded evidence in terms of the TPACK framework.

Most of the participants demonstrated some evidence reflecting each of the three types of IWB feature usage and each combination of the technology-relevant TPACK categories. Many participants described their IWB usage in pure pedagogical terms by offering explanations in which they could easily replace the term *mathematics* (content) with another content area. I classified most of the participants' demonstrated IWB usage as digital accentuation because it involved little, if any, change in participants' existing approaches to instruction other than highlighting some visual characteristic of the mathematics. Those participants typically used IWB features such as colored pens and highlighters because they were easy to access and were not considered messy.

Considering mathematics inherently represents an interrelated content, I do not find it surprising to have found evidence of participants' intentions to use the IWB in a manner that reflects mathematics as having multiple representations and connections across grade levels. After recoding the data for evidence of TPACK in which all three knowledge types (technology, pedagogy, and mathematics content) coincided, I identified a consistent relevance to problem solving, a recognized component of a rigorous mathematics learning experience. Ideally, "students should have frequent opportunities to formulate, grapple with and solve complex problems that require a significant amount of effort and should then be encouraged to reflect on their thinking" (NCTM, 2000, p. 52). By viewing problem solving from the perspective of the TPACK-coded evidence, I propose that the study's findings offer insights into how teachers make IWB-based instructional decisions. In essence, if a teacher's instructional goal is to enact IWB-based lessons involving student-centered problem solving, that instruction needs to reflect the concurrence of all three TPACK domains.

Primary Conclusions

I drew four primary conclusions from the present study: (a) the identification of an IWB usage classification scheme; (b) experienced secondary mathematics teachers are more likely to use IWBs to enact established instructional methods, rather than identify new ones; (c) the nature of students' shared IWB usage appeared restricted to presenting more visually colorful presentations of the mathematics; and (d) teachers who shared the IWB with their students for problem solving typically involved the concurrence of all three TPACK knowledge domains. Each of these conclusions offers insight on how IWBs can support effective teaching of mathematics with the support of IWBs.

IWB usage categories. My first conclusion involves the organizational approach that I developed and used to partition my findings into three separate IWB usage categories. By consistently probing the participants as to why they used a particular IWB feature, I collected data about the participants' explanations and preferences. Because the majority of the sample represents self-proclaimed visual learners, it is not surprising that these participants wanted their students to literally see mathematical relationships. Moreover, they used this visual instructional tool to produce visual displays of mathematics in the same way they wanted their students to see it. In essence, they were *digitally accentuating* the look of the mathematics because they wanted to draw attention to it.

I derived the second classification, digital proximity, from the evidence depicting participants' demonstrations of IWB usage to visually present the interrelatedness of mathematics. At first, I observed participants explicitly referencing the need to promote the multi-representational creed of functions: numerical, symbolical, and graphical. With further probing, some participants expressed the desire to relegate portions of the mathematics to another digital page. It was as if they believed moving some part of the lesson content to either the same or separate viewing screen helped to promote or dispute various mathematical relationships or misconceptions. These participants appeared to believe their students' understanding of mathematical connectedness would be secured if the lesson's visual presentation maintained boundaries consistent with mathematical structures, also referred to as *digital proximity*.

Because I came to this study with an interest in exploring how teachers share the IWB with their students, I persistently probed my participants for insights into how and why students' ideas about the mathematics appeared on the IWB. All of the participants expressed some interest in having students share their mathematical thinking during whole-class discussion. The challenge perceived by several of the participants was how to facilitate student-centered work that was problematic in nature. For example, some of the participants expressed concerns with time management and students' work being illegible or promoting misconceptions. These participants resolved those problems by having the students use IWB features that were easy to undo or instantly erase visible traces of problematic mathematics. Whether student-centered problem solving took on a nonlinear process of brainstorming or included incorrectly annotated analysis, the participants expressed the remedy as a guilt-free way to *digitally enable the exploration* of the mathematics.

Old methods. When considering the IWB teaching trajectory model (Betcher & Lee, 2010; Miller, Glover, & Averis, 2004), all participants in the present study demonstrated IWB usage predominately consistent with the first two phases of the IWB developmental journey, supported didactic (old methods in old ways) and interactive (old methods in new ways). I am not surprised to see evidence of this type of usage; however, I am concerned about seeing how much of this form of IWB-based instruction dominated the post-video interview discussions. I found this observation especially concerning in light of my efforts to purposefully select participants representing teachers who had significant amounts of instructional experience using IWBs and who showed evidence of using student-centered instruction.

The experienced secondary mathematics teachers in my study were more likely to use IWBs to enact established instructional methods rather than identify new ones. I derived that conclusion because most participants noted the IWB's instructional value predominately in terms of time saving and ease of use. Moreover, IWBs offered participants a way to accomplish more of what they always have attempted to do when facilitating whole-class discussion. I routinely heard participants' reasoning that involved explanations of how IWB features offered a way for them to share mathematics with their students that involved gaining easier access to presentation tools, not necessarily developing new methods to explore mathematics concepts.

My efforts to further classify evidence in terms of the various TPACK domains reinforced this view as many of the participants' statements reflected an emphasis on technological-pedagogical knowledge with less attention to the mathematical content aspects. In essence, those participants used IWB features predominately to automate their instructional actions rather than to portray mathematics as dynamic.

The student side of sharing. Based on my conception of sharing, I expected to see more evidence of teachers working with students together at the IWB. Instead I mostly observed teachers and students taking turns at the IWB with students using colored pens and backgrounds. Considering the vast array of ways to use IWBs interactively involving movement, model-manipulation, and multi-media, this form of color-relevant sharing appeared superficial. In spite of not seeing more variation in the ways students used the IWB, I probed all of my participants for whether they observed their students using the IWB to visually present mathematical relationships using the various digital pagination features. The typical reaction was a blank stare. It is unclear to me as to whether they did not expect students to use the IWB in that manner or whether their students did not have enough practice using the IWB to feel competent with those other IWB features.

I did observe an exception to this pattern of sharing that involved the undo feature. Most students demonstrated ease and confidence with this particular feature when problem solving at the IWB. Without reservation, most students quickly tapped a back-button icon whenever they felt the need to erase a previously written part of their mathematics. I hypothesize that the students freely engaged in this form of instant-erasing because that IWB feature is similar to the one found on personal computers, not because they viewed problem solving as a messy cognitive process in which mathematicians have many false starts or need to backtrack a few steps to fix errors during the solution process.

TPACK view of student-centered sharing. The fourth conclusion centers on my interpretation of how the participants used IWB features to promote an appreciation for and to encourage practice with problem solving. Most of the evidence I classified as teacher knowledge reflecting all three TPACK domains involved some form of problem solving. These lessons portrayed problem solving as something to model, to explore mathematical reasoning, or to share authority while conducting it. Even though I did not observe all participants inviting their students to share the IWB for problem solving, when the topic arose during interviews with participants who I did not observe using the IWB in this manner, 3 participants expressed interest in this approach to problem solving. Unfortunately, some of those participants offered descriptions of IWB usage that was limited to being able to spontaneously present different forms of the mathematics instead of descriptions of lesson plans that included either of those approaches to problem solving. My concern is that in order for teachers to truly engage in student-centered sharing, they will need to approach IWB usage in a manner that involves the concurrence of the full suite of TPACK domains. Such a perspective involves IWB-based instruction with more planning and less spontaneity.

Implications

These conclusions offer value to three different communities engaged in efforts relevant to mathematics education: the teacher education, the professional development, and the professional learning communities. Each group should consider: (a) the proposed framework for classifying IWB feature usage, (b) the potential need to emphasize higher levels of IWB usage such as digital proximity and digitally enabled exploration as a form of instruction and sharing, and (c) the emphasis on teachers needing to engage the full set of TPACK knowledge domains when making decisions to include student-centered problem solving in their lessons. Mathematics education organizations can gain value from these conclusions in their efforts to support teachers' effective use of educational technology.

First, teacher educators can benefit from understanding how IWBs can provide instructional value when designing curriculum with regard to mathematics. Whether the teacher education curriculum separates or integrates educational technology into the coursework, teacher preparation instructors need insights into how to position the value of IWB features in terms of the mathematical content being taught. Specifically, teacher educators can focus technology relevant instruction by modeling IWB usage in ways that emphasize the interrelatedness of mathematics and student-centered problem solving.

Next, because school systems continue to make investments in professional development, they need to explore options that go beyond enlisting equipment manufacturers to sponsor and conduct workshops on how to use IWBs as a generalized instructional tool. The findings of this study offer specific insights targeting mathematics instruction. Without attending to them, such professional development is likely to remain generic and not offer pedagogical value specific to mathematics education.

Last, teachers and teacher organizations frequently share ideas through online peer groups or professional organizations. If these professional learning communities used the IWB usage framework presented in this study, the national discourse on teaching mathematics with IWBs might engage in more activities promoting technology-based instruction reflecting consideration for TPACK. Similarly, these types of communities can encourage members to articulate their IWB-based best practices using the proposed framework's vocabulary as a way of drawing attention to NCTM's (2000) standards and principles associated with reformed views on mathematics education.

Limitations

As with all research studies, this one has limitations. I purposefully chose participants who had significant experience levels in teaching mathematics, embraced technology in their practice, and favored student-centered instructional strategies. Although this choice of a purposeful sample profile aligned well with a study designed to explore IWB-based instructional strategies, it does nothing to illuminate the nature of IWB-based instruction associated with teachers who represent different dispositions. In essence, do the findings of this study apply exclusively to teachers who meet all three of these requirements or does it have applicability to other profiles?

Unfortunately, the study's design to prequalify the 8 participants as experienced IWB users resulted in the identification of only a few innovative ways to use IWBs in support of mathematics instruction. Although the study presented insights into how the participants used TPACK-based decisions in support of their IWB usage, the participants demonstrated more usage aligned with streamlining their existing methods of instruction than with sharing an exploration of the mathematics with their students. For the most part, all 8 participants expressed interest in sharing the IWB for this purpose. In particular, during the preliminary interviews they referenced using a variety of student-centered instructional methods such as student-lead discussions and individualized problem-solving activities using graphing calculators or laptops. In spite of these testimonials, 6 participants explained their planning efforts of retooling their instructional materials to accommodate curricula changes dominated most of their lesson planning time. I believe it is foreseeable that without that time-consuming obstacle, these participants would have had more time to plan new methods in new ways involving the IWB.

According to the extant literature on IWB pedagogical usage, teachers follow a developmental trajectory. Researchers of these studies do not claim teachers will evolve through the developmental cycle. They suggest only that the cycle exists. So what motivates teachers to develop effective use of instructional technology? In this vein of thinking, I propose that it is far more likely for school system administrators to be interested in how to encourage their technology-apprehensive faculty to use the installed IWB equipment more productively, or possibly at all. For that reason, this study's limitations include a lack of relevance to teachers either lacking appropriate professional development or espousing teacher-centered philosophies. Is it reasonable to think that teachers who do not favor technology-based instruction or who choose not to share the IWB with their students would still gravitate toward more productive IWB-based strategies if their professional development modeled mathematics-specific instructional techniques? That is the type of question school administrators face when considering budget allocation involving teachers' professional development. In spite of this institutional need to focus on the weaker link, I believe a benchmark is necessary. This study establishes a profile of IWB instructional use for professional development models.

Future Research

This study involved secondary mathematics teachers and their instructional efforts with the support of IWBs. Some of the findings of this study may be relevant to all grade levels. Subsequent studies involving a similar methodology with an elementary school sample would illuminate similarities and differences in how teachers at both grade bands use IWBs to support their mathematics instruction.

A second area for future research consideration involves exploring how IWBs support teachers' formative assessment efforts. This study centered on exploring how mathematics teachers use IWBs to elicit student thinking. When teachers give students opportunities to experience and practice using IWBs as a form of sharing mathematics as a whole-class learning experience, teachers can observe students' actions as a reflection of their thinking. I propose that my conclusions offer foundational perspectives for future studies designed to explore how teachers can use IWBs as a formative assessment tool. Just as formative assessment involves a sequential assessment process in which teachers identify students' levels of understanding as input to determining next steps, the IWB offers a tool for exposing student thinking whenever students use its features in a nonsuperficial way.

Parting Thoughts and Reflections

Prior to conducting this study, I had a sense of what teachers' instructional practices might look like when using IWBs. Because my data collection process involved going back and forth among multiple participants, I found myself routinely comparing one participant's approach to that of another. I found my use of video-stimulated recall interviews as a data collection technique to be generative for my participants as well as for myself. Not only did I find my own thoughts progressively taking shape with each new VSR interview, I also detected my participants' reflective thoughts evolving. It was not uncommon for some of my participants to express a reconsideration of how they shared the IWB with their students after examining their video-recorded instruction. Frequently they described the realization that their observed instructional approaches limited students' mathematics to presentation instead of exploration.

Prior to participating in this study, one highly technology-experienced participant recognized that she restricted her ideas on IWB feature usage to how she understood the mathematics with no consideration for how students viewed the IWB as a tool to interpret mathematics. She, along with 2 other participants, typically encouraged students to choose a colored pen or background color. Only in a few cases did I observe participants sharing the IWB in such a way that students displayed their mathematics as dynamic or interactive. In order for teachers to reap greater instructional value from IWB usage, they need to go beyond using it as a presentation tool. Rather, they need to enact lessons in which they share control of this instructional tool with their students.

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APPENDIX A

STAGES OF CONCERN QUESTIONNAIRE

Name ____

The purpose of this questionnaire is to determine what high school teachers, who are using interactive white boards to teach mathematics, are concerned about at various times during the adoption process of this type of educational technology.

The items were developed from typical responses of school and college teachers who ranged from no knowledge at all about various innovations to many years' experience using them. Therefore, **many of the items on this questionnaire may appear to be of little relevance or irrelevant to you at this time**. For the completely irrelevant items, please circle "0" on the scale. Other items will represent those concerns you do have, in varying degrees of intensity, and should be marked higher on the scale.

For example:

This statement is very true of me at this time.	0	1	2	3	4	5	6	7
This statement is somewhat true of me now.	0	1	2	3	4	5	6	7
This statement is not at all true of me at this time.	0	1	2	3	4	5	6	7
This statement seems irrelevant to me.	0	1	2	3	4	5	6	7

Please respond to the items in terms of **your present concerns**, or how you feel about your involvement with **interactive whiteboards**. We do not hold to any one type of an interactive whiteboard, so please think of it in terms of your own perception of what it involves. The phrase "this approach" refers to teaching mathematics with an interactive whiteboard as the innovation. Remember to respond to each item in terms of your present concerns about your involvement or potential involvement with interactive whiteboards.

Thank you for taking time to complete this questionnaire.

		Circle One Number for Each Item
1.	I am concerned about students' attitudes toward using the interactive whiteboard in the mathematics classroom.	0 1 2 3 4 5 6 7
2.	I now know of some other approaches to using the interactive whiteboard that might work better for teaching mathematics.	0 1 2 3 4 5 6 7
3.	I am more concerned about teaching mathematics with a type of educational technology other than the interactive whiteboard.	0 1 2 3 4 5 6 7
4.	I am concerned about having enough time to organize myself each day.	0 1 2 3 4 5 6 7
5.	I would like to help other faculty in their use of the interactive whiteboard.	0 1 2 3 4 5 6 7
6.	I have a very limited knowledge of teaching mathematics with interactive whiteboards.	0 1 2 3 4 5 6 7
7.	I would like to know the effect teaching mathematics with an interactive whiteboard will have on my professional status.	0 1 2 3 4 5 6 7
8.	I am concerned about conflict between my approach to teaching mathematics and my responsibilities with using the interactive whiteboard.	0 1 2 3 4 5 6 7
9.	I am concerned about revising my approach to teaching mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
10.	I would like to develop working relationships with both our faculty and outside faculty who teach mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
11.	I am concerned about how teaching with the interactive whiteboard affects students' learning of mathematics.	0 1 2 3 4 5 6 7
12.	I am not concerned about teaching mathematics with an interactive whiteboard at this time.	0 1 2 3 4 5 6 7
13.	I would like to know who will make the decisions about teaching mathematics with interactive whiteboards.	0 1 2 3 4 5 6 7

		Circle One Number for Each Item
14.	I would like to discuss the possibility of teaching mathematics with an interactive whiteboard.	0 1 2 3 4 5 6 7
15.	I would like to know what resources are available if we decide to adopt interactive whiteboards.	0 1 2 3 4 5 6 7
16.	I am concerned about my inability to manage all the features and functions of an interactive whiteboard.	0 1 2 3 4 5 6 7
17.	I would like to know how my teaching mathematics is supposed to change with the use of an interactive whiteboard.	0 1 2 3 4 5 6 7
18.	I would like to familiarize other mathematics teachers with the instructional benefits of using interactive whiteboards.	0 1 2 3 4 5 6 7
19.	I am concerned about evaluating my impact on student learning of mathematics.	0 1 2 3 4 5 6 7
20.	I would like to revise the way others teach mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
21.	I am preoccupied with things other than teaching mathematics with interactive whiteboards.	0 1 2 3 4 5 6 7
22.	I would like to modify our approach to teaching mathematics with interactive whiteboards based on the experiences of our students.	0 1 2 3 4 5 6 7
23.	I spend little time thinking about teaching mathematics with interactive whiteboards.	0 1 2 3 4 5 6 7
24.	I would like to excite my students about their learning mathematics with an interactive whiteboard.	0 1 2 3 4 5 6 7
25.	I am concerned about time spent working with nonacademic problems related to teaching mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
26.	I would like to know what the use of the interactive whiteboard for teaching mathematics will require in the immediate future.	0 1 2 3 4 5 6 7

		Circle One Number for Each Item
27.	I would like to coordinate my efforts with others to maximize the interactive whiteboard's effects.	0 1 2 3 4 5 6 7
28.	I would like to have more information on time and energy commitments required for teaching mathematics with an interactive whiteboard.	0 1 2 3 4 5 6 7
29.	I would like to know what types of mathematics other faculty are teaching with interactive whiteboards.	0 1 2 3 4 5 6 7
30.	Currently, other priorities prevent me from focusing my attention on teaching mathematics with an interactive whiteboard.	0 1 2 3 4 5 6 7
31.	I would like to determine how to supplement, enhance, or replace my approach to teaching mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
32.	I would like to use feedback from students to change the way I teach mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
33.	I would like to know how my role will change when I am teaching mathematics with the interactive whiteboard.	0 1 2 3 4 5 6 7
34.	Coordination of interactive whiteboard tasks that support my lesson plans is taking too much of my time.	0 1 2 3 4 5 6 7
35.	I would like to know how the interactive whiteboard can enhance the way we teach mathematics now.	0 1 2 3 4 5 6 7

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APPENDIX B

LEVELS OF UNDERSTANDING INTERVIEW PROTOCOL

Interview Participant Name: _______________________________

Date/Time of Interview: _________________

Thank you for making time to meet and support my research program. This interview will take approximately 30 minutes.

Before we start the interview, I would like to get your consent on this set of documents [Share duplicate copies of the consent form]. They provide a written record of my agreement to maintain confidentiality with your personal information and responses. I will be audio-recording this interview for further analysis in support of my research efforts. Any reference to this interview data will be described using pseudonyms such as a "secondary high school mathematics teacher" or "a suburban neighborhood of a southeastern part of the United States".

At any time, you can withdraw your participation and have the results of this interview removed from the research records or destroyed. If you should have any concern regarding your responses to a *particular* question and would like this specific *portion* of the interview removed from the data collection, I can strike this specific response from the recorded data.

This first interview involves a series of sequenced questions that may seem repetitive. This is deliberate so that I can deeply explore your thoughts, intentions, and recollections associated with your experience using interactive whiteboards. If anything is not clear, please ask. I am happy to restate any of the questions.

Before we start the interview, do you have any questions of me?

[Interview Protocol]

Introduction	*Q1A: Are you currently using the interactive whiteboard in your mathematics teaching?* IF NO: This answer is not anticipated, as participants have been pre-screened for affirmative IWB usage. IF YES: Proceed to Q1B.
	Q1B: What course(s) are you currently teaching that involve the use of the interactive whiteboard? Follow-up probes: *Please describe this/these course/s?* *How long have you been teaching this course in a manner that involves using the interactive whiteboard?*
	Q2: In as much detail as you recall, please describe a particular lesson when you included the use of the interactive whiteboard to support student learning? Follow-up probes: *What math concepts are associated with this lesson?* *Which IWB features did you use? (Provide a copy of the IWB feature checklist.)* *Who used the IWB during this lesson?* *Did the students have any documents or manipulatives that were a part of the IWB experience? If yes, please describe.*
Assessing & Knowledge	*Q3A: What do you see as the strengths and weaknesses of using an interactive whiteboard in support of teaching mathematics?* Follow-up probes: *Please describe the way(s) the interactive whiteboard <u>strengthens</u> student learning?* *Please describe the way(s) the interactive whiteboard <u>weakens</u> student learning?*

Assessing & Knowledge	*Q3B:* *Have you made any attempt to do anything about the weaknesses?* Follow-up probe: *If yes, please describe this experience.*
Acquiring Information	*Q4A:* *Are you currently looking for any information about how to teach mathematics with interactive whiteboards?* Follow-up probes: *What kind of resources have you looked for?* *For what purpose?*
Sharing and Decision Point E	Q5: *Do you ever talk with others about teaching mathematics with an interactive whiteboard?* Follow-up probes: *If yes, who?* *What do you tell them?*
Assessing	Q6A: *What do you see as being the consequences of using the interactive whiteboard?* Follow-up probe: *In what way have you determined this?*
Assessing	Q6B: *Are you evaluating, either formally or informally, your use of the interactive whiteboard?*
Assessing	Q6C: *Have you received any feedback from students about using the interactive whiteboard?* Follow-up probe: *What have you done with the information you get?*
Status Reporting and Performing	Q7: *Have you made any changes recently in how you use the interactive whiteboard?* Follow-up probes:

	If yes, *please describe these changes.* *Why did you make these changes?* *How recently did you make these changes?* *Are you considering making any additional changes? (If yes, recycle this series of questions.)*
Type of Orientation? (User/Self, None, Client)	*Q8A: What kinds of changes to your approach to teaching mathematics are you making that are related to your use of the interactive whiteboard?* Follow-up probes: *If Yes, probe to determine whether these changes are teacher- or student-centric.* *If teacher-centric, wrap up interview.* *If student-centric, please describe how these changes influence your efforts to teach mathematics.* *If NO change, probe for nature of routine use (teacher- or student-centric)?*

[Closing]

Thank you for taking the time to participate in this interview.

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APPENDIX C

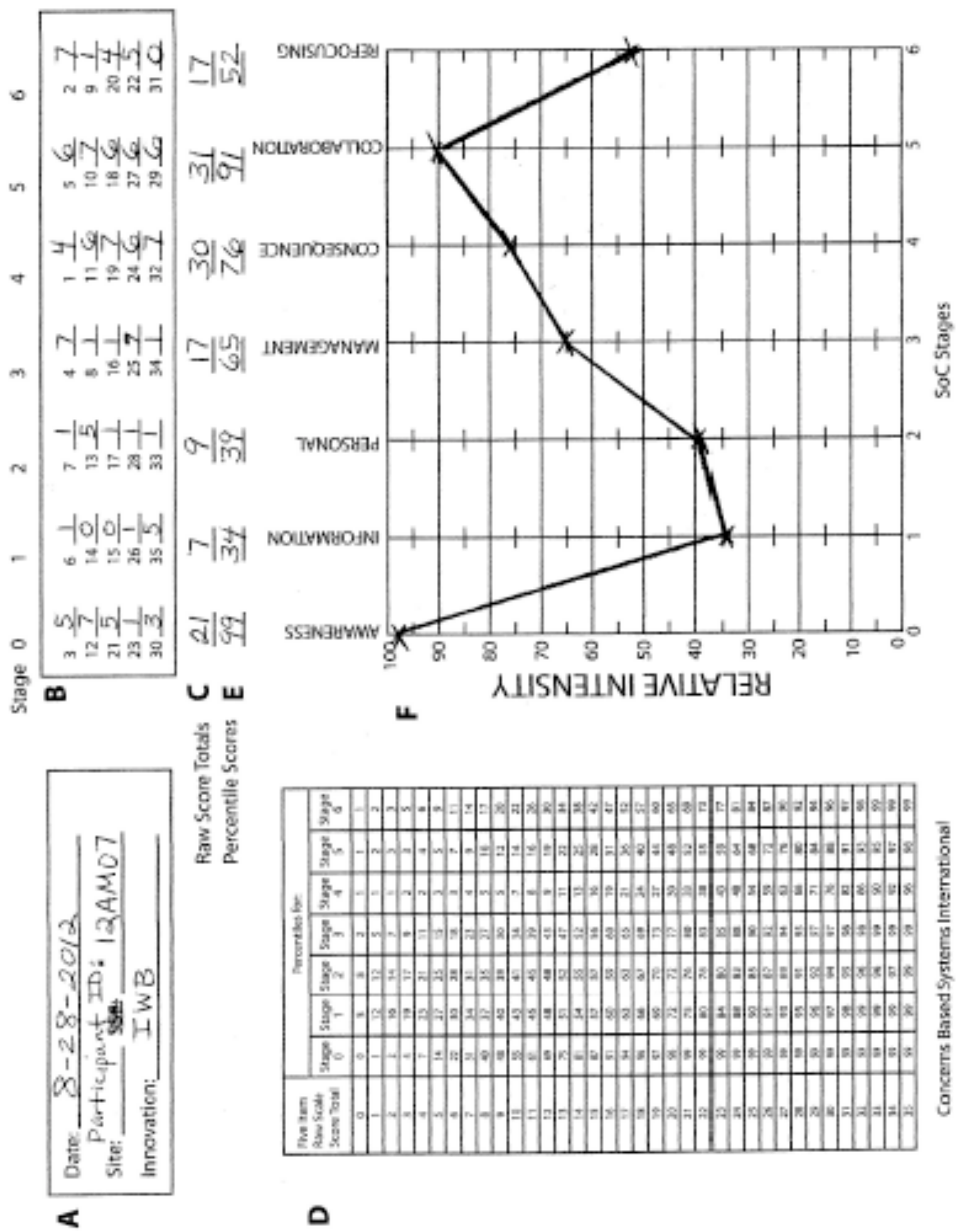
INTERACTIVE WHITEBOARD FEATURE CHECKLIST

IWB Feature/Technique Name	**Functional Description**
Drag-ability (Moving)	○ Being able to drag objects around the screen ○ Involves moving, sorting, classifying or matching things
Hide and Reveal (IWB sliding opaque screen, dragging opaque images)	○ Visually stacking objects in a particular order so that one object is able to obscure the object below. ○ Hiding and revealing by covering information with a layer
Reorganizing screen images (cut-and-paste, shrink/enlarge, cloning)	○ Changing screen images in ways to that involve changing the size and orientation ○ Duplicate screen images
Layer screen	○ Overlay a transparent layer on top of existing content (includes other applications such as PowerPoint and Word) to allow easy annotation
Digital pagination (Extend page, Scroll up and down, New Page)	○ A series of screens that can be flipped as individual pages, forward and backward ○ Easy access to pages can be on an as-needed basis ○ Extending IWB screen to include content beyond viewable screen
Wide range of pen colors, Shading, and highlighter tools	○ Annotating images ○ Highlighting text on web pages ○ Calling out important elements ○ Using arrows/lines or graph grids to present graphical representations
Instant eraser (back button, IWB eraser, undo)	○ Instantly erasing annotations in the same order applied to IWB screen ○ IWB eraser (adjustable size)
Digging into the gallery (equipment library)	○ Access electronic library of clip-art type images, photos, background images, videos, sounds, shapes, lines and interactive simulations ○ Mathematics tools (graphing grids, compass, protractor)

Digital Hub	○ Integrating additional equipment for display on IWB screen (document cameras) ○ Displaying other applications on IWB screen (dynamic geometry software applications, graphing calculator screens, online applications)
Toggling between multiple IWB screens (includes split-screen feature)	○ Accessing multiple views through IWB I in a back-and-forth fashion (point-and-click) ○ Shrinks 2 active IWB screens for viewing on a single IWB page
Adding media to the mix	○ Access to online media (video clips, photo images, animated applets)
IWB accessory equipment	○ Wireless tablet interface (slate/tablet or i-Pod mini with third party software) ○ Handheld laser pointer ○ Electronic podium interface to IWB (control station)

APPENDIX D

STAGES OF CONCERN QUICK SCORING DEVICE SAMPLE



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