AN ABSTRACT OF THE DISSERTATION OF

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Title: The Development of Pre-Service Teachers' Technology Specific Pedagogy.

Abstract approved:

Margaret L. Niess

The purpose of this study was to document the development of pre-service teachers' Technology Specific Pedagogy as they learned to teach mathematics with technology during their initial licensure program. The study investigated the pre-service teachers' learning using both a social and a psychological perspective of teacher learning. Two research questions were used to guide the research:

1. What patterns of participation are displayed across learning contexts as pre-service teachers reason pedagogically about teaching mathematics with technology prior to their full-time student teaching?
2. In what ways do the Technology Partnership Project and its features facilitate pre-service mathematics teachers' development of TPCK?

The pre-service teachers shared ideas that gave insight into their reasoning about teaching with technology, their overarching conception of teaching mathematics with technology and their knowledge of students' understanding, thinking, and learning in mathematics with technology.

Five pre-service teachers were followed during coursework and participation in the Technology Partnership Project field experience. Course participation, course assignments, team planning meetings, teaching observations,

teaching artifacts, and interview transcripts were documented and analyzed as evidence of the development of pre-service teachers' Technology Specific Pedagogy. Three pre-service teachers were purposefully selected for in-depth case analysis.

The study identified four patterns of participation as the three case participants reasoned about teaching with technology: *Playing to Learn*, *Lesson Design*, *Student Control*, and *Equitable Access*. The pre-service teachers also shared ideas that indicated their overarching conception of teaching mathematics with technology: *Doing to the Technology* versus *Using the Technology,* and *Technology as an Extension/Simplifier* versus *Technology as Enhancer/Differentiator*. Lastly, the pre-service teachers shared repeating ideas that indicated their knowledge of students' understandings, thinking, and learning with technology: *Visualizing with Technology*, *Abstraction with Technology*, and *Motivation*.

Certain features of the Technology Partnership Project facilitated the development of the pre-service teachers' thinking, including: (1) opportunities to advocate for their own ideas and convince others of the validity of those ideas, (2) opportunities to teach using the ideas of their peers and the in-service teachers and to learn from those ideas, and (3) a way to connect preconceptions about the way students learn with actual examples of student learning.

The Development of Pre-Service Teachers' Technology Specific Pedagogy

by
Rachel A. Harrington

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Rachel A. Harrington, Author

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My first, and best,

Mathematics teacher.

For William H. Pawuk

The consummate

Lifelong learner.

For Ryan C. Harrington

Who never stopped telling me

I should,

I could,

I would.

The Development of Pre-Service Teachers' Technology Specific Pedagogy

CHAPTER ONE

THE PROBLEM

Teaching with technology can facilitate the types of instruction in current calls for reform in mathematics education (Association of Mathematics Teacher Educators (AMTE), 2007; International Society for Technology in Education (ISTE), 2003; National Council of Teachers of Mathematics (NCTM), 2005). Thoughtful use of technology can enable the learning of both mathematical content and processes detailed in the *Principles and Standards for School Mathematics* (NCTM, 2000). If children are to have access to these types of learning experiences, then learning to teach with technology must be a critical component of teacher preparation. Standards have been established to define what pre-service teachers need to know by the completion of their teacher preparation program (ISTE, 2003). Additionally, researchers have identified and described the knowledge needed to teach mathematics with technology (Margerum-Leys & Marx, 2002; Mishra & Koehler, 2006; Niess, 2005). While there has been discussion and understanding of what teachers need to know in order to teach mathematics with technology, there is less of an understanding of *how they develop this knowledge*. This research study explicitly examined how mathematics pre-service teachers developed the knowledge for teaching mathematics with technology through an examination of their experiences in a program designed specifically to integrate theory and practice by linking university coursework and field experiences.

Reform movements from within the mathematics community have called upon teachers to design learning experiences that develop a rich understanding of mathematical content in their students (NCTM, 2000). In the US, many school districts have invested significant resources to acquire instructional tools that help teachers meet the standards set forth by NCTM. A significant portion of this investment has gone towards the purchase of instructional technology including: various calculators, computers with mathematical software, Internet connectivity, handheld data collection devices, and sensing probes. For the purposes of this paper, this class of tools will be hereafter called *technology*. It is precisely this technology that allows students to extend the types of mathematics they study and enhances their learning of the mathematical content (NCTM, 2005; Wenglinsky, 1998).

Technology eases the process of data collection and analysis. It enhances computation and representations of mathematical ideas that allow students' access to mathematics in realistic settings that facilitate higher order thinking skills (NCTM, 2005). The International Society for Technology in Education (ISTE) is a nonprofit membership organization, providing leadership and service to improve teaching, learning, and school leadership by advancing the effective use of technology in K-12 schools and teacher education. ISTE contends that technology allows students to meet a wide variety of learning objectives including reflection, reasoning, problem posing, problem solving, and decision making (ISTE, 2007). In fact, NCTM's *Principles and Standards for School Mathematics* and ISTE's newly revised *National Educational Technology Standards for Students* (NETS-S)[1] are similar in many ways (ISTE, 2007; NCTM, 2000). Both speak strongly of a need for students to develop mastery of operations and concepts through communication, collaboration, critical thinking, and problem-solving. The use of technology in mathematics instruction can be one way to facilitate these mathematical processes. Instructional fluency with a wide range of technology should be in the pedagogical toolkit of every teacher.

Effective Teaching with Technology

Teachers who effectively use technology in their mathematics instruction share a number of characteristics (Niess, 2005). These teachers have a strong knowledge of three domains: mathematics, pedagogy and technology. Furthermore, teachers who effectively integrated technology have knowledge of

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[1] See Appendix A for full text of the NETS-S

how these three domains interact. This knowledge can be observed through four characteristics.

First, these teachers have developed a rich knowledge base and firm beliefs about the role of technology in teaching mathematics. For these teachers, math lessons are designed to meet content objectives and the purpose of the technology tool is facilitate student learning (Pierson, 2001). Learning to use technology is not the driving force in planning lessons. In fact, for these teachers, regular planning routines do not change when technology is used. In these classrooms, technology is used thoughtfully, selectively, and regularly.

A second characteristic that strong technology integrators share is a deep knowledge of strategies and representations for teaching mathematics with technology. When given mathematical content, these teachers can identify a variety of technology that can help students to understand specific aspects of that content. For example, they can describe how the slope of a line can be explored through lessons that use motion sensors, graphing calculators, or spreadsheets. They are also able to recognize the benefits and drawbacks of using various representations to meet individual student needs.

Teachers who effectively integrate technology into instruction also have a rich understanding of how technology can impact the way students learn mathematics. These teachers recognize the potential that technology has for assisting students to visualize mathematical concepts, make connections between mathematical representations, and develop their abstract thinking (Bakker & Frederickson, 2005). They also recognize the motivating factor that technology can have on student engagement and interest in the subject of mathematics (Vincent, 2005).

Finally, strong technology integrators are familiar with the wide range of technology tools, both hardware and software, that can be used to teach various mathematical concepts. They understand that certain technology is more effective for different mathematical content and also for different developmental levels of students. They are comfortable navigating and using new technology and take time to reflect on ways that this new technology can fit into the existing curriculum.

Learning to Teach with Technology

Teachers must learn to effectively integrate technology into their mathematics instruction, and this learning should begin during initial licensure. *Technology integration* is "[t]he seamless, day-to-day connection of technology to instruction for the purpose of supporting and extending curriculum objectives and to engage students in meaningful learning" (ISTE, 2003, p. 218). Integrating technology into instruction is not a trivial task. In fact, organizations like the Association of Mathematics Teacher Educators (AMTE) have called for licensure programs to critically examine the ways that they are working to prepare teachers to use technology. The complexity of technology integration means that learning to teach with technology should be a significant component of the teacher preparation process (AMTE, 2007; NCTM, 2005; Niess, 2006).

ISTE has defined specific technology standards that apply to classroom teachers (ISTE, 2003). The *National Educational Technology Standards for Teachers* (NETS-T) include six standard categories: (1) Technology Operations and Concepts, (2) Planning and Designing Learning Environments and Experiences, (3) Teaching, Learning and the Curriculum, (4) Assessment and Evaluation, (5) Productivity and Professional Practice, and (6) Social, Ethical, Legal and Human Issues[2]. Taken together, these standards capture the broad consensus among the education community of what a teacher should know and be able to do with technology. Within these standards, teacher performance profiles have been created to help teacher preparation programs design and assess the development of their pre-service teachers as they work to meet the standards.

Similar to student benchmarks, performance profiles have been written to describe what teachers should know and be able to do before entering a teacher preparation program (*General Preparation*), at the end of coursework (*Professional Preparation*), at the end of the culminating field experience *(Student*

[2] See Appendix B for full text of the NETS-T

Teaching/Internship), and at the end of their first year of teaching (*First-Year Teaching*) (ISTE, 2003). Teacher preparation programs shoulder most of the responsibility for helping prospective teachers meet the *Professional Preparation Performance Profile*[3]. While preparation programs can continue to influence pre-service teachers during student teaching and early teaching, it is during coursework when programs can have the most impact.

Even with the availability of the NETS-T and the Performance Profiles, little research has been done to assess the effectiveness of specific teacher preparation program components in meeting these goals. The NETS-T standards represent the best thinking of experts in the field. However, the majority of the research that has been done at this point has focused on reporting on and describing projects, with little focus on developing the knowledge needed for teaching mathematics with technology.

If pre-service teachers are to meet these standards, they need more than just a knowledge of their content, knowledge of technology, or knowledge of effective pedagogical strategies. Instead, they require a knowledge that is a synthesis of all three knowledge bases. Building on the work around the knowledge needed for teaching, researchers have characterized this knowledge needed for teaching with technology as Technological or Technology Pedagogical Content Knowledge (TPCK) (Margerum-Leys & Marx, 2002; Mishra & Koehler, 2006; Niess, 2006). TPCK is more than being proficient with technology for personal use and productivity. Rather it is "…an understanding of how technology can be integrated with subject matter and the technology itself" (Keating & Evans, 2001, p. 2).

In order for teachers to integrate technology into their teaching in a thoughtful and productive way, they must rely on their TPCK. Work specific to the development of TPCK has advocated for the potential of university coursework to enhance this knowledge (Holahan, Jurkat, & Friedman, 2000; Niess, 2005; Suharwoto & Lee, 2005). If university coursework is a place to cultivate TPCK, then identification of specific examples of this cultivation is needed. Such models

[3] See Appendix C for full text of the Professional Preparation Performance Profile

would take into account the process through which people learn to teach, while facilitating the development of the knowledge needed to teach. Unfortunately, the literature is deficient in the analysis of the effectiveness of specific models of the cultivation of TPCK in the teacher preparation programs.

Developing TPCK in Teacher Preparation Programs

The literature describes a range of approaches to the development of TPCK during teacher preparation. One approach used by many programs is to offer a single technology course that focuses on methods for integration (Hargrave & Hsu, 2000). A second option is to make technology assignments a component of a variety of courses throughout the licensure program and into field experiences (Pope, Hare, & Howard, 2002). Finally, a third approach integrates technology across the entire program (Wetzel, Zambo, & Buss, 1996). This third approach builds on the others and offers pre-service teachers the opportunity to see innovative uses of technology modeled and encouraged throughout all coursework and field experiences. This third approach is the least common, but examples can be found in the literature (Niess, 2005; Wetzel et al., 1996).

The institution in this study offers a one-year graduate level program that leads to a Master's of Science degree and state teacher licensure in mathematics or a science content area for grades 3-12. Pre-service teachers entering the teacher preparation program at this institution hold an undergraduate degree in either mathematics or a science related field. Each year, the cohort typically consists of around 30 pre-service teachers. This particular licensure program is offered by a department of science and mathematics education housed in a college of science.

In this professional teacher education program, there are four significant time phases of learning. The first, Phase I, begins with three weeks of full-day coursework that introduces common themes of teaching. These themes include unit and lesson design, learning theories, professionalism, and classroom management. This first phase concludes with a one month, full-time initial field placement. The next phase, Phase II, includes both coursework and field experiences. For these months, the teacher candidates interact in their initial field placement in the morning and in coursework in the afternoons. Their coursework includes classes that address science/mathematics methods, pedagogy, subject matter, and adolescent psychology. Phase III consists of full time coursework with class assignments that involve short-term field experiences. During the fourth and final phase, the pre-service teachers are in a second field placement full time. This phase is often described as "full time student teaching."

The teacher preparation program in this study makes a conscious commitment to the development of the pre-service teachers' ability to use technology in an effective way. This commitment is realized through department established standards[4], coursework requirements, and instructor modeling (Science and Mathematics Education Department, 2006). This particular program aligns with the range of approaches for developing TPCK during teacher preparation that were outlined above. In this licensure program, the development of TPCK is accomplished through stand alone courses (approach 1) and technology components integrated into a number of courses (approach 2).

For the past two years, mathematics students in the pre-service teacher cohort have participated in the Technology Partnership Project as part of a course requirement. A variety of goals direct this project. First, the teacher preparation program intends to give pre-service teachers an opportunity to develop their TPCK in an authentic and supportive environment. Second, the preparation program aims to support local area in-service teachers in their growth as technology integrators. Finally, all stakeholders hope to give the K-12 students access to rich mathematics experiences through the use of available, but underused, technology resources.

The Technology Partnership Project pairs a local area in-service teacher volunteer with two pre-service teachers to develop a mathematics unit that utilizes the K-12 school's available technology to teach scheduled curriculum. For this project, in-service teachers provide information about the curriculum and

[4] Program Standard 8.0 Technology: The program will ensure that teachers of science and mathematics have skills in using technologies and can engage students in learning science and mathematics using appropriate technological resources to expand the science and mathematics knowledge.

classroom context in which the lesson is to be taught. The pre-service teachers provide insight into the ways that the technology might be used to enhance the instruction of the planned curriculum. Taking turns, each pre-service teacher takes the lead to teach individual lessons to the in-service teacher's middle school students. The in-service teacher is an integral member of the instructional team, answering student questions, and providing logistical support.

This project is intended to provide opportunities for pre-service teachers to develop their ability to integrate technology into instruction. In addition, it is an explicit example of how the licensure program aims to synthesize educational theory with teaching practice. It is precisely this type of synthesis that shows the most promise in helping to develop a teacher's knowledge base (Adler, 2000; Szabo, Scott, & Yellin, 2002). The extent to which this project idea succeeds in meeting these goals remains unclear. Specifically, questions arise as to whether and how the Technology Partnership Project helps the pre-service teachers develop their TPCK and meet the benchmarks outlined in the *Professional Preparation Participation Profile (ISTE, 2003)*.

The Situated Nature of Learning to Teach

Learning is a process that by its nature is situated. In other words, how a person learns something and the context in which it is learned are fundamental to *what* that person learns (Greeno et al., 1996). The central importance of context in the learning process can be illustrated more clearly by looking at a person learning to teach school mathematics. Learning to teach mathematics takes place across a number of contexts: subject matter courses, educational theory and methods courses, field experiences, and informal gatherings of colleagues (Peressini, Borko, Romagnano, Knuth, & Willis, 2004).

In order to adequately characterize the situated learning of pre-service mathematics teachers as they learn to teach and learn to teach with technology, researchers need to examine the teachers' learning trajectory across all the contexts or situations in which it takes place (Putnam & Borko, 2000). Methods courses provide opportunities for students to experience reform teaching practices

(Grossman, 1990; Jones & Vesilind, 1996; Lowery, 2002). Field experiences allow access to in-service teachers' craft knowledge (Bannan-Ritland, 2003; Borko & Putnam, 1996; Cope & Stephen, 2001; Feiman-Nemser, 2000; Guyton & McIntyre, 1990; McIntyre, Byrd, & Foxx, 1996). Additionally, pre-service teachers learn from interactions with peers (Bullough et al., 2003). Specific projects infused into the pre-service program (such as the Technology Partnership Project) can provide opportunities for methods courses to align with field experiences while pre-service teachers interact with their peers in the process of developing their knowledge, skills, and dispositions for integrating technology into instruction.

These varying contexts for learning indicate that in order to characterize the development of a pre-service teacher's knowledge base, the development must be examined in context of coursework, field experiences and peer interactions. This development can be captured in many ways including: (1) an analysis of the way pre-service teachers defend their ideas in their reflections and coursework, (2) the way they justify their thinking to peers, instructors and cooperating teachers, and (3) through the choices they make during their own teaching. All of these taken together help to define *patterns of participation* across the learning contexts of peer interaction, coursework and field experiences as pre-service teachers are learning to teach mathematics with technology (Peressini et al., 2004).

Research grounded in cognitive theories of learning considers the individual as the unit of analysis, while the situative perspective looks instead to group interactions to analyze learning. More recently, some have argued that researchers should be looking at both individual and group processes depending on the purpose of the research (Cobb & Bowers, 1999; Cobb & Yackel, 1996; Peressini et al., 2004). When applied to teacher preparation, this *emergent perspective* characterizes learning to teach as a process where the individual pre-service teacher develops the knowledge needed to teach, while simultaneously developing his or her identity as a part of a wider society of teachers. Cobb et al.'s emergent perspective affords researchers the ability to characterize both the cognitive components of learning to teach (goals, values, commitments, knowledge, beliefs) along with the sociocultural components (how teachers participate, present themselves in communities, patterns of interactions) (Peressini et al., 2004). Such a perspective suggests a method for researchers in characterizing these social and psychological components with respect to developing the ability to teach mathematics with technology. Such a method would take into account the changing ideas of individual students, as well as the influence that social interactions have on these ideas and their growth.

Statement of the Research Problem

Rather than attending to whole program considerations of developing TPCK, research is needed that studies specific components of programs. Particularly, programs that are purposefully designed to develop the pre-service teachers' knowledge, skills, and dispositions for teaching mathematics with appropriate technologies in ways that support student learning should be investigated. The problem for this study was to capture the learning and understandings of pre-service teachers as they participate in the Technology Partnership Project embedded in their teacher preparation program.

The learning and understandings of pre-service teachers can be studied using both the social and the psychological perspectives. Capturing patterns of participation across various contexts demonstrates their learning on the social plane (Borko et al., 2000; Greeno, Collins, & Resnick, 1996; Peressini et al., 2004; Putnam & Borko, 2000). Thus, given the situated nature of learning, this study must take place across a number of contexts in order to adequately identify the impact of this project: field experiences, content courses, methods and pedagogy courses, and peer interactions (Borko et al., 2000; Peressini et al., 2004; Putnam & Borko, 2000). An analysis of the knowledge needed for teaching mathematics with technology (TPCK) demonstrates learning on the psychological plane (Borko et al., 2000; Peressini et al., 2004). Therefore, the study must look at the individual understandings of the pre-service teachers as well.

Considering both the social and psychological perspectives involved in learning to teach mathematics with technology, the following questions direct this research:

1. What patterns of participation are displayed across learning contexts as pre-service teachers reason pedagogically about teaching mathematics with technology prior to their full-time student teaching?
2. In what ways do the Technology Partnership Project and its features facilitate pre-service mathematics teachers' development of TPCK?
   2.1 In what ways does the Technology Partnership Project contribute to pre-service teachers' overarching conception of teaching mathematics with technology?
   2.2 In what ways does the Technology Partnership Project contribute to pre-service teachers' knowledge of students' understandings, thinking, and learning in mathematics with technology?

Significance of the Study

One measure of the significance of a study is to examine how it simultaneously answers two questions. First, how does this work move educational theory forward? Second, how does this work move educational practice forward? This study takes place across a number of contexts to examine both the individual and social aspects of learning to teach mathematics with technology. These contexts include those that emphasize educational theory and those that demand an ability to participate in educational practice. In the past, teaching was seen as a trade and learning to teach required an apprenticeship model. However, learning to teach is more than learning to copy behaviors. The field is in need of frameworks that address the complexity of learning to teach. This study offers a framework that acknowledges this complexity and facilitates its analysis in the preparation of mathematics teachers to teach with technology.

The literature offers little insight into how teacher preparation programs can develop TPCK through explicit integration of field experiences and university coursework. By expanding on the field's understanding of the role of context in learning to teach with technology, this study examines an explicit model that can be used by those directing teacher preparation programs as they work toward the *Professional Preparation Performance Profile* (ISTE, 2003). A key feature of this Technology Partnership Project model is that it emphasizes the integration of educational theory (coursework) as well with educational practice (field experiences). More specifically, this study aims to develop sound educational theory that can lead to effective practice. At the same time, the practice of the pre-service and in-service teachers informs the viability of the educational theory.

CHAPTER TWO

REVIEW OF THE LITERATURE

The purpose of this literature review is to position this study in the existing body educational research. The review begins with an overview on learning to teach and how coursework and field experiences influence this process. Teacher preparation involves the development of a person's Professional Identity, Content Specific Pedagogy, and Content Knowledge (Peressini et al., 2004). This chapter shows how this development manifests itself as pre-service teachers learn to teach mathematics with technology. The chapter concludes with the description of a theoretical framework that takes into account both social and psychological aspects of learning to teach with technology.

Contexts for Developing Domains of Professional Expertise

In 1991, NCTM challenged teacher preparation programs to model good teaching, help teachers develop knowledge of content, offer good learning theory, and help pre-service teachers develop their identities as teachers (NCTM, 1991). In response, some in the education community have organized these challenges into three *Domains of Professional Expertise*: (1) Professional Identity, (2) Content Specific Pedagogy, and (3) Content Knowledge (Peressini et al., 2004). Investigations designed from a situated perspective on learning can shed light on whether licensure programs are meeting these challenges.

The situated perspective is based on the idea that learning is situated and that how and where a person learns an idea are a fundamental part of *what* is learned (Greeno et al., 1996). This perspective contends that in order to understand learning, the learning must be considered from the multiple contexts and must take into account the individual as well as the physical and social systems in which learners participate (Putnam & Borko, 2000). If the goal is to study the process of learning to teach and the development of the Domains of Professional Expertise, then a variety of contexts where pre-service teachers learn must be considered: subject matter courses, methods courses, and field experiences (Borko et al., 2000; Feiman-Nemser, 2000).

University coursework is a context over which teacher preparation programs have the most control. Preparation programs are challenged with developing course sequences that focus on quality over quantity. Typically, pre-service teachers are required to take subject matter courses (in mathematics, for example) and education courses (such as methods or educational psychology courses). These preparation programs are challenged to find a way to balance the content courses and theory courses in order to achieve the most impact on the pre-service teachers.

Clear evidence exists, however, that just requiring more subject matter courses is insufficient to impact teacher practice in mathematics (Ball, 1990; Ball, Lubienski, & Mewborn, 2001; Grossman, Wilson, & Shulman, 1989). Carefully designed subject matter courses that explicitly focus on making mathematics available to learners, attending to student ideas, and promoting a mathematical discourse show promise at impacting teacher practice and their students' achievement Some education programs work closely with the university mathematics departments to embed the mathematics content within ideas of promoting mathematical discourse. In spite of this, some content courses might have little if any link to the context of skills important in teaching.

The theory presented in methods courses has the potential to impact pre-service teacher practice in both the field experience and early career teaching (Grossman, 1990; Jobe & Pope, 2002; Suharwoto & Lee, 2005). However, it is often difficult for pre-service teachers to see the value in educational theory if it is presented in a way that is disconnected from practice (Feiman-Nemser, 2000). Methods courses that are disconnected from the reality of a classroom are often offered as explanation for why so many teachers value their field experiences over their coursework (Guyton & McIntyre, 1990).

Field experiences are a ubiquitous component of most every teacher preparation program (McIntyre et al., 1996). While these experiences can take on a variety of forms, most aim to offer an opportunity for pre-service teachers to apply educational theory while accessing the craft knowledge held by practicing in-service teachers (Cope & Stephen, 2001). Difficulties arise when the goals of the preparation program are in conflict with the goals of the cooperating teacher (Feiman-Nemser, 2000; Frykholm, 1998). In-service teachers sometimes feel inclined to “protect” their student teachers from the pressures of the university requirements, and in turn require little in the way of reform based instruction (Feiman-Nemser, 2000; Frykholm, 1996).

University coursework and field experiences are the primary components of most teacher preparation programs. Yet, each component in isolation is insufficient to adequately prepare pre-service teachers for the work of teaching. The literature points toward conceptual and structural alternatives that can help to strengthen the impact of teacher preparation. One conceptual alternative is to actively link coursework with field experiences. The literature indicates that both coursework and field experiences can be significantly enhanced and improved when there is an explicit attempt to integrate them (Jones & Vesilind, 1996; Putnam & Borko, 2000; Szabo et al., 2002).

A structural alternative that can also impact practice is to place pre-service teachers into field experiences with peers rather than in isolation. Pre-service teachers can learn from peer interactions in a way that is different from the learning that takes place in coursework and field experiences (Sumsion & Patterson, 2004). In a study of pre-service teachers who did their student teaching with a partner, Bullough et al. (2003) found that the pre-service teachers were able to synthesize their coursework and field experiences more effectively and their relationships with the cooperating teacher were more collaborative in nature. This alternative also seems to facilitate the development of a communal perspective on teaching and assists in problem solving for the pre-service teachers (McIntyre et al., 1996).

Professional Identity and Teaching Mathematics with Technology

In their work, Peressini et al.(2004) identify *Professional Identity* as one Domain of Professional Expertise. Professional Identity is defined as the goals, values, commitments, knowledge, and beliefs that a teacher holds. It includes his or her personal characteristics and it shapes how a particular teacher addresses problems of practice. Teacher preparation programs are charged with actively helping pre-service teachers to begin the development of their Professional Identity. The work of Cobb and his colleagues has illustrated that learning processes can be viewed by using both a social and a psychological perspective (Cobb & Yackel, 1996). This emergent perspective helps us to view the development of a teachers' Professional Identity as well. In the case of learning to teach mathematics with technology, Professional Identity can be examined from both a social and a psychological perspective. Table 2.1 describes both perspectives.

Table 2.1: Professional Identity

Domain of Professional Expertise	**Social Perspective**	**Psychological Perspective**
Professional Identity	Pedagogical Social Norms	Teacher's beliefs about own role, others' role and general nature of technology

Professional Identity from a social perspective consists of the *Pedagogical Social Norms* that a teacher holds. Pedagogical Social Norms can be thought of as a mutual engagement and agreement on social norms and norms specific to mathematics teaching. They include the shared repertoire and normative ways of reasoning with resources (like technology) when planning for instruction (Dean, 2006). As with norms of any kind, Pedagogical Social Norms develop over time as group members interact with one another. Thus, documenting this development requires spending time with a group collecting data on social interactions and examples of conflict and negotiation (McNeal & Simon, 2000).

From a psychological perspective, Professional Identity manifests itself through the *teacher's beliefs about his or her own role, others' role and general nature of technology*. A teacher's beliefs are different than a teacher's knowledge. Beliefs exert the existence of some phenomenon. For example, a teacher might believe that success depends on ability. This belief might contrast with reality, and be based on some specific past experience or event (Calderhead, 1996). Unlike knowledge, beliefs are affective and evaluative. They are episodic and often associated with some event or experience that the teacher has had. Calderhead (1996) also points out that beliefs have significant impact on the teaching roles and practices that teachers adopt, and are very difficult to change. However, changing beliefs is most effective when teachers are helped to adopt a new practice and see that this practice is successful.

Technology Specific Pedagogy for Teaching Mathematics

A second Domain of Professional Expertise is *Technology Specific Pedagogy* (Peressini et al., 2004). Examples of Technology Specific Pedagogy might include how a teacher selects appropriate technology for a given lesson, or how a teacher manages discourse during a lesson that uses technology. Teachers who display strong Technology Specific Pedagogy are teachers "…possessing the unique ability to understand, consider, and choose to use technologies *only* when they uniquely enhance the curriculum, instruction and students' learning" (Hughes, 2004, p. 346). These teachers use their subject matter knowledge, pedagogical knowledge and pedagogical content knowledge to "…identify promising, innovative ways technologies may be used to teach their subject area discipline to K-12 students" (Hughes, 2004, p. 346). Technology Specific Pedagogy can also be analyzed using both a social and psychological perspective. Table 2.2 describes these perspectives.

Table 2.2: Technology Specific Pedagogy

Domain of Professional Expertise	Social Perspective	Psychological Perspective
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Teacher's overarching conception of teaching content with technology
		Teacher's knowledge of student understandings, thinking, and learning a subject with technology

There are social indicators of Technology Specific Pedagogy and they can be seen through the development of *Norms of Pedagogical Reasoning about Technology*. These norms govern the way a group reasons about pedagogical choices related to teaching with technology. Norms of Pedagogical Reasoning govern how classroom teaching practices comes to be known, shared and developed by teachers in their interactions (Little, 2003). Examples of norms of pedagogical reasoning can be seen as units of teacher-to-teacher talk where the teachers exhibit their reasoning about an issue in their practice, when they describe issues in or raise questions about teaching practice, and in their explanations and justifications (Horn, 2005). While the existence of these norms for pedagogical reasoning about teaching with technology seems clear, their evolution and description remains under-examined.

The psychological perspective reveals Technology Specific Pedagogy in two ways. The first is through the *teacher's overarching conception of teaching content with technology*. The second is the *teacher's knowledge of student understandings, thinking, and learning a subject with technology*. These are two of the four components of Technology Pedagogical Content Knowledge (TPCK) (Niess, 2005).

A teacher's overarching conception of teaching mathematics with technology can have a powerful influence on the way instruction unfolds in the classroom Pierson (2001) found three perspectives that were commonplace among teachers who used technology in their teaching of mathematics. Instructional time with technology was viewed as time to "do the computers", use the computer to do an activity, or do an activity that used the computers. In each case, the teachers' own definition of technology integration directed their management of computer use whether it was integrated thoughtfully and selectively on a regular basis, used as a center activity or as time allowed, or used as a reward activity.

A pre-service teacher's overarching conception of teaching with technology can be influenced by carefully selected activities that give him or her an opportunity to plan, carry out, and reflect on lessons that use technology (Angeli & Valanides, 2005; Lundeberg, Bergland, Klyczek, & Hoffman, 2003). Changes to their overarching conception can be more meaningful when they take place in the real context of a K-12 classroom (Hughes, 2005; Lowery, 2002).

A second way that the psychological perspective gives insight into a pre-service teachers' Technology Specific Pedagogy is by their knowledge of student understandings, thinking and learning mathematics with technology. The use of technology in mathematics instruction has been shown to impact student motivation, ease the investigation of large data sets that cannot be manipulated by hand, and allow for quick changes to mathematical representations (Bakker & Frederickson, 2005). Technology allows students to move between concrete and abstract examples, motivating them to look beyond procedural calculations and more toward concepts of proofs and advanced questioning (Vincent, 2005). Understanding the ways that technology impacts student learning is a key component to developing a pre-service teacher's Technology Specific Pedagogy.

Content Knowledge for Teaching Mathematics with Technology

The particular *Content Knowledge* needed for teaching is the third Domain of Professional Expertise (Peressini et al., 2004). The National Educational Technology Standards for Teachers (NETS-T) highlight Content Knowledge in the first standard *Technology Operations and Concepts* (ISTE, 2003). As with the previous two Domains of Professional Expertise, Content Knowledge can be viewed using both a social and a psychological perspective. Table 2.3 illustrates these perspectives.

Table 2.3: Content Knowledge

Domain of Professional Expertise	Social Perspective	Psychological Perspective
Content Knowledge	Classroom Pedagogical Practices With Technology	Teacher's knowledge of instructional strategies and representations for teaching with technologies
		Teacher's knowledge of curriculum and curricular materials

Content Knowledge can be examined using a social perspective by observing the pre-service teachers' *Classroom Pedagogical Practices with Technology*. These practices can be described as patterns of thought and action that have been established by participants in particular contexts or settings (Cobb & Bowers, 1999). In other words, these patterns emerge among the group in terms of how they think about and act out pedagogically with technology. These practices develop over a period of time and can be captured by observing group actions and how they come to agree upon certain ways of teaching with technology tools.

One model for developing pedagogical practices with technology calls for a three phase approach (Holahan et al., 2000). Phase one is a "mentor the mentor" process where districts commit to supporting the integration of technology, offer workshops and guided practice for mentors, and mentors integrate technology into their own classes. Phase two is a diffusion phase where mentors plan and meet with other building teachers and the mentees experiment in their own classes. Phase three involves the "institutionalization" technology integration where districts call for regular technology use from their teachers.

Content Knowledge needed for teaching with technology can also be analyzed through a psychological perspective. Two components of the psychological perspective for Content Knowledge are the remaining two components of TPCK (Niess, 2005). The first is the *teacher's knowledge of* *instructional strategies and representations for teaching with technologies*. The second is the *teacher's knowledge of curriculum and curricular materials*.

Teachers with a strong knowledge of instructional strategies and representations for teaching with technologies share certain common characteristics (Pierson, 2001). These teachers use computers for personal tasks, have had a lot of opportunities for professional development, and are surrounded by supportive colleagues and a supportive district. Furthermore, they use technology to redefine teaching and learning roles and to solve educational problems. The standards and performance profiles found in the NETS-T documents also serve as tools to describe this type of teacher in detail (ISTE, 2003).

Professional development for teachers on integrating technology into instruction must go beyond mere skill development (Mishra & Koehler, 2006). The rapid pace with which technology advances means basic skills can quickly become obsolete. Furthermore, the situated nature of teaching is context bound, so generic uses of technology are not as helpful in developing content specific skills for integrating the technology. Guidelines have been set forth on how this knowledge can be developed by both in-service teachers and pre-service teachers (Hughes, 2004). Learning opportunities should (1) be connected to a teacher's practice, (2) be tied to specific content, (3) include opportunities for reflection, and (4) allow teachers choice in what they want to learn.

Knowledge of curriculum and curricular materials is the second psychological component of the Content Knowledge needed to teach with technology. In mathematics this knowledge might include how certain aspects of a curriculum, like lines of best fit or the connection between right triangles and trigonometry functions, can be explored using software like *Geometer's Sketchpad* (Knuth & Hartmann, 2005). It could also be an understanding of how spreadsheets can be used to sort data, graph it, and make calculations in order to answer specific questions generated by the children (Caulfield, Smith, & McCormick, 2005). Technology must be applied cautiously in the early grades (Clements & Sarama, 2005), but even elementary number sense ideas can be enhanced through the thoughtful use of handheld calculators (Kierman & Guzman, 2005).

Developing the knowledge of curriculum and curricular materials in mathematics is a career spanning activity (Ma, 1999). This understanding is equally true of how this curriculum can be taught using technology (ISTE, 2003). Teachers need to begin this process in their licensure programs and continue enhancing it throughout their careers.

A Conceptual Framework for Learning to Teach with Technology

Up to this point, this chapter has focused on how the three Domains of Professional Expertise (Professional Identity, Technology Specific Pedagogy, and Content Knowledge) can be analyzed using both a social perspective and a psychological perspective. This expertise takes into account how the domains manifest themselves as norms and practices in social interactions, beliefs, and the knowledge needed to teach with technology (TPCK). Taken together, these three components provide a framework for studying how pre-service teachers learn to teach with technology. Table 3.4 shows how each Domain of Professional Expertise fits in the Learning to Teach with Technology (LTT) Framework.

Table 3.4: The Learning to Teach with Technology (LTT) Framework

Domain of Professional Expertise	Social Perspective	Psychological Perspective
Professional Identity	Pedagogical Social Norms	Pre-service teacher's beliefs about their own role, others' role and the general nature of technology
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Pre-service teacher's overarching conception of teaching mathematics with technology
		Pre-service teacher's knowledge of student understandings, thinking, and learning mathematics with technology
Content Knowledge	Classroom Pedagogical Practices With Technology	Pre-service teacher's knowledge of instructional strategies and representations for teaching with technologies
		Pre-service teacher's knowledge of curriculum and curricular materials

Taking into account both the social and psychological perspective, the LTT Framework provides a way to look at teacher preparation through a situated lens. The situative perspective allows the investigation of "...the properties of individual's cognition and behavior that support their contributions to the functioning of the systems in which they participate" (Greeno & MMAP, 1998, p. 7). Examining pre-service teachers' learning through a situated perspective means looking for examples of consistent performance, understandings of what it means to know content, expectations that pre-service teachers have of their success and failure, their level of engagement in activities and participation in discussions, and whether they contribute to mutual understandings by appreciating and explaining assumptions (Greeno, 2003). The LTT Framework allows for the unit of analysis to change from the individual to the group depending on the needs of the researcher. This flexibility allows the researcher to capitalize on all of the available evidence, both social and individual, in order to adequately characterize this learning.

The LTT Framework also provides further evidence that the psychological and social views of learning are not in conflict with one another, but should instead be thought of as reflexive and mutually dependent (Cobb, Stephan, McClain, & Gravemeijer, 2001). The framework accounts for a pre-service teacher's individual development as it occurs in the social contexts of coursework and field experiences. The social perspective captures the collective classroom processes while the psychological perspective relates the individual activity as the pre-service teachers "…participate in and contribute to the development of these communal processes" (Cobb & Yackel, 1996, p. 196). This way of "blending" the social and the psychological aspects of learning has been called for by the situated perspective (Greeno et al., 1996). The focus on how each can provide insight to the other is truly a shift from thinking about cognitive and social learning theories are different (Greeno & MMAP, 1998).

Linking the LTT Framework to this Study

The teacher preparation program in this study provided a variety of opportunities for the pre-service teachers to develop each of the areas of the framework and these opportunities happened both in coursework and field experiences, especially during the Technology Partnership Project. However, exploring each of these opportunities and how they contribute to the entire LTT Framework is beyond the scope of this project. Rather than provide a "mile wide inch deep" picture of how teachers learn to teach with technology, this project will focus specifically on how these teachers develop their Technology Specific Pedagogy. Table 2.5 highlights the focus of this study.

Table 2.5: The Focus of this Study

Domain of Professional Expertise	Social Perspective	Psychological Perspective
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Pre-service teacher's overarching conception of teaching mathematics with technology
		Pre-service teacher's knowledge of student understandings, thinking, and learning mathematics with technology

In Chapter One: The Problem, the two research questions that guided this study were presented. These two research questions were directly linked to the framework for Technology Specific Pedagogy. The first question targeted the social perspective of Technology Specific Pedagogy: Norms of Pedagogical Reasoning about Technology. The second question was linked to the psychological perspective of Technology Specific Pedagogy. The sub-questions 2.1 and 2.1 were directly connected to the two sub-components of the psychological perspective: the overarching conception of teaching with technology and the knowledge of students' learning with technology.

Changes to a pre-service teacher's overarching conception can be more meaningful when taken place in the real context of a K-12 classroom (Hughes, 2005; Lowery, 2002). Furthermore, authentic field experiences and the craft knowledge that in-service teachers can offer during activities like the Technology Partnership Project have real potential for influencing a pre-service teacher's conception of teaching with technology. At this time, the impact the Technology Partnership Project has on pre-service teachers' TPCK is unclear.

The literature suggests that in order to have an impact on a teacher's TPCK, learning opportunities should (1) be connected to a teacher's practice, (2) be tied to specific content, (3) include opportunities for reflection, and (4) allow teachers choice in what they want to learn (Hughes, 2004). Each of these guidelines informed the design of the Technology Partnership Project. The lessons were connected to the in-service teacher's practice and the teams determined the most appropriate technology to learn. Also, the activity was tied to content that was specific to the curriculum and culminates with opportunities for formal and informal reflection. The process for analyzing the impact on the participants' TPCK is presented in the next chapter.

CHATPER THREE

METHODS

The purpose of this study was to capture and describe the learning and understandings of pre-service teachers as they participated in the Technology Partnership Project embedded in their teacher preparation program. Specifically, the pre-service teachers' development of Technology Specific Pedagogy was the primary focus. The methods in this study aimed to characterize the patterns of participation displayed across learning contexts as pre-service teachers reasoned pedagogically about teaching mathematics with technology prior to their full-time student teaching. More specifically, the research questions were as follows:

1. What patterns of participation are displayed across learning contexts as pre-service teachers reason pedagogically about teaching mathematics with technology prior to their full-time student teaching?
2. In what ways do the Technology Partnership Project and its features facilitate pre-service mathematics teachers' development of TPCK?
   2.1 In what ways does the Technology Partnership Project contribute to pre-service teachers' overarching conception of teaching mathematics with technology?
   2.2 In what ways does the Technology Partnership Project contribute to pre-service teachers' knowledge of students' understandings, thinking, and learning in mathematics with technology?

The research was also designed to collect data necessary to determine the ways that the Technology Partnership Project and its features facilitated pre-service mathematics teachers' development of TPCK. In other words, the study analyzed how this model contributed to pre-service teachers' overarching conception of teaching mathematics with technology and their knowledge of students' understandings, thinking, and learning in mathematics with technology. The research questions were directly correlated to the components of Technology Specific Pedagogy. Table 3.1 reminds the reader of the components of

Technology Specific Pedagogy, both from the social and psychological perspective.

Table 3.1: The Focus of this Study

Domain of Professional Expertise	**Social Perspective**	**Psychological Perspective**
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Pre-service teacher's overarching conception of teaching mathematics with technology
		Pre-service teacher's knowledge of student understandings, thinking, and learning mathematics with technology

The first research question focused on the investigation of pre-service teachers' Technology Specific Pedagogy through the social perspective. Research question two focused on the psychological perspective, while questions 2.1 and 2.2 addressed each sub-component of the psychological perspective.

This study analyzed the learning of pre-service teachers across a number of learning contexts using both a psychological and a social perspective. The questions in this study aimed to characterize the learning that pre-service teachers have during coursework and the Technology Partnership Project. The purpose was to determine whether these activities were developing their Technology Specific Pedagogy and to give insight in to why and how these were developing.

This particular study occurred during the third iteration of the Technology Partnership Project and was the first formal study of the project. The multiple authentic contexts in which this study took place included university coursework, team planning meetings and K-12 classrooms. This study had at its center an orientation toward providing a usable example of how theory could inform practice.

In this study, data were collected including surveys, university classroom observations, artifact collection, team planning observations, and individual interviews with pre-service teachers. This chapter provides specific descriptions of the participants, research sites, and data collection that occurred in the study. The chapter concludes with a description of the purpose of each type of data collected and how that data was analyzed.

Study Design

Research Sites

The LTT Framework that guided this study was based on a situated perspective of learning (Peressini et al., 2004). This perspective suggests that learning occurs across a number of contexts. Specifically, how a person learns something and the context in which it is learned are fundamental to *what* that person learns (Greeno et al., 1996). Therefore, characterizing the way that pre-service teachers developed their Technology Specific Pedagogy throughout fall and winter term program work provided a means for tracing their learning trajectory across a number of research sites.

Two primary research sites were observed during this study. The first research site was a teacher preparation course titled Technology and Pedagogy I. The institution in this study offered a one-year graduate level program that led to a Master's of Science degree and state teacher licensure in mathematics or a science content area for grades 3-12. The context for this licensure program was a department that provided science and mathematics content-specific teacher preparation housed in a college of science. The Technology and Pedagogy I course was taken by all students, mathematics and science majors alike, enrolled in the annual licensure cohort. The pre-service teachers in this program entered the program with varying levels of Technology Specific Pedagogy. The purpose of the Technology and Pedagogy I course was to develop pedagogical content knowledge in science and mathematics education focused on the integration of technology in teaching and learning for grades 3-12. This course met five times during the fall quarter of the licensure program. Each class meeting lasted for two hours.

The second primary research site was the middle school classrooms in which the Technology Partnership Project lessons were taught. The school site was in a university town of around 60,000 people. At this site, two different classrooms were part of the Technology Partnership Project. Both classrooms were seventh grade general mathematics classes. One class was taught by Ms. Thomas[5], an experienced teacher who was new to this particular middle school. The second classroom belonged to Ms. Sanders. She was nearing the end of her teaching career and had been at the middle school for a number of years. Each year, Ms. Sanders takes one or two student teachers from the licensure program in this study. She had also participated in the Technology Partnership Project during the first year it was formed.

Participants

The pre-service teacher participants were selected from the mathematics students enrolled in the licensure program. Five pre-service teachers were selected based on their interest in participating. Background information on the participants' knowledge of technology was collected at the end of the Technology and Pedagogy I course. To collect this information, the ISTE General Preparation Profile for Prospective Teachers Survey (ISTE, 2003)[6] was administered to all participants. This survey asked participants to assess their ability to integrate technology into instruction. It was intended that the pre-service teacher participants were selected in such a way that included a mix in gender and abilities in technology and mathematics.

The Technology Partnership Project created teams of three pre-service teachers matched with volunteer in-service teachers. For this study, two in-service teachers participated. These in-service teachers, Ms. Thomas and Ms. Sanders, were volunteers from the partner middle school. In the past, both teachers had acted as cooperating teachers for the licensure program in this study. Both teachers were identified by the licensure program as having strong content and

[5] All names of participants are pseudonyms.
[6] See Appendix D for complete versions of the ISTE General Preparation Profile for Prospective Teachers Survey

curriculum understanding and the in-service teachers provided that knowledge to the pre-service teachers during the Technology Partnership Project. The selected in-service teachers did not have an especially strong Technology Specific Pedagogy, but both had a strong desire to develop this pedagogical form.

The university instructor who taught the Technology and Pedagogy I course, Mr. Compton, was an important part of this study. While Mr. Compton did not contribute as a participant in a traditional sense, he did aid in the participant selection and structuring of classroom activities. During the research study, informal but regularly occurring meetings between the researcher and the instructor helped to inform the data collection by providing insight into the instructor's purpose for assignments and goals for instruction. For these reasons, Mr. Compton was considered both a co-researcher and participant.

Research Methods

Data Collection

In this study, a variety of data were collected across a number of learning contexts in order to answer the research questions. Table 3.2 details the data that were collected, when they were collected, and how much was collected.

Table 3.2 Data Collection Matrix

Data	Date	Amount
ISTE General Preparation Profile for Prospective Teachers Survey	10/24/07	N=5
Video from Technology and Pedagogy I	09/26/07 to 10/24/07	Ten hours
Student work from Technology and Pedagogy I	09/26/07 to 10/24/07	Six discussion board postings and five assignments per participant
Classroom artifacts from Technology and Pedagogy I	09/26/07 to 10/24/07	Syllabus, schedule, eight teaching demonstration documents, five assignment descriptions
Classroom artifacts from Problem Based Learning	01/11/08 to 01/17/08	Syllabus, schedule, assignment description
Audio recording of team planning sessions	01/14/08 to 02/21/08	Team 1: Eight meetings Team 2: Three meetings
Audio recording of individual interviews	02/21/08 to 02/28/08	N=5
Video from Technology Partnership Project teaching	01/16/08 to 2/21/08	Team 1: Eight classes Team 2: Five classes
Teaching materials from Technology Partnership Project	01/16/08 to 2/21/08	Team 1: Eight lesson plans; Two worksheets; Three teaching demonstration documents; Final assessment Team 2: Six lesson plans; Two worksheets; Three teaching documents

The first phase of data collection occurred during the Technology and Pedagogy I course. This class met weekly for five weeks during the fall term of the academic year. Each class meeting was two hours in length. All class meetings were videotaped. A camera captured all large group instruction and discussion. During small group work, the camera was focused on the small group that contained the most number of mathematics education majors who had agreed to participate in the study. During each class meeting, the researcher collected field notes that marked "times of interest" for further analysis. Times of interest were episodes where interactions or discussions occurred that potentially related to the research questions. The purpose of these observations was to examine pre-service teachers' patterns of participation in a content course. Furthermore, the researcher hoped to use this data to aid in tracking the development of the Norms of Pedagogical Reasoning about Technology that formed in the group of mathematics pre-service teachers.

The instructor of the Technology and Pedagogy I course designed learning activities with the purpose of influencing the pre-service teachers' overarching conception of teaching mathematics with technology. This influence was documented by an analysis of the artifacts from the course. Therefore, during the Technology and Pedagogy I course, classroom artifacts were collected. These artifacts included the course syllabus, instructional documents, and any learning materials provided by the instructor.

All of the coursework of the participant pre-service teachers was collected during the Technology and Pedagogy I course. This work included course discussion board reflections and course assignments that were regular part of the assigned worked of the course. These documents served to document the pre-service teachers' overarching conception of teaching mathematics with technology and their knowledge of student understandings, thinking, and learning mathematics with technology at this point in their learning. The collection of pre-service teachers work provided data from the psychological perspective on their developing Technology Specific Pedagogy.

Additional data collection occurred during the Problem Based Learning course where the Technology Partnership Project occurred. This course met for only two face-to-face class meetings. The researcher attended these meetings and took field notes. Artifacts including the course syllabus, course schedule, and assignment description were collected. After the initial two weeks, the class adjourned so that students could work full time in their field placements. For the participants in this study, that field placement was the Technology Partnership Project.

The next major phase of data collection occurred during the Technology Partnership Project. At the start of this project, in-service teacher and pre-service teacher teams met to plan the teaching unit. These meetings were audio-recorded and transcribed in their entirety. The primary purpose of this data collection was to document the pre-service teachers' patterns of participation in this context. Also, this activity provided another opportunity to capture how the pre-service teachers displayed Norms of Pedagogical Reasoning about Technology.

During the project, the pre-service teachers taught their lesson sequences with the assistance of the in-service teacher. The team working with Ms. Thomas taught for eleven class meetings, eight of which used technology during instruction. The team working with Ms. Sanders taught for seven class meetings, six of which used technology during instruction. All of these lessons that included technology as a teaching or learning tool were videotaped as they occurred in the classroom. The focus of the video was on the pre-service teachers' practice. Care was taken to not identify K-12 students in the video. The primary purpose of this data was to characterize the pre-service teachers' patterns of participation in this context. These observations served as a method for connecting the pre-service teachers' overarching conception of teaching mathematics with technology and their knowledge of student understandings, thinking, and learning mathematics with technology to their practice.

In addition to teaching together, the two groups planned in their teams as well. During the Technology Partnership Project, Ms. Thomas' group met daily after the lesson to reflect on that day's progress. These meetings were also used to plan for the next day's activities. These meetings, eight in all, were audio recorded and transcribed. The researcher observed the meetings and took field notes marking times of interest for further analysis. Ms. Sanders' group did not meet this way. Twice, the team talked briefly at the end of the class and these were the only planning records that were recorded after the initial planning meeting.

Part of the Technology Partnership Project requirements included submission of lesson plans and student materials necessary for teaching the lessons. These artifacts were also collected for this study. These documents allowed the researcher to correlate what was planned for the lesson and what actually happened when the lesson was taught. The purpose of this data collection was to document the pre-service teachers' overarching conception of teaching mathematics with technology and their knowledge of student understandings, thinking, and learning mathematics with technology.

The Technology Partnership Project concluded with a formal opportunity for the pre-service teachers to reflect on the project. The participants completed individual post-interviews with the researcher to further probe for their overarching conception of teaching mathematics with technology and their knowledge of student understandings, thinking, and learning mathematics with technology. The goal of these interviews was to understand what pre-service teachers knew, not to "grade" them (Heid, 1999). Thus, only the researcher (who did not have grading responsibilities) conducted these interviews. Each of the five pre-service teachers completed a 30-45 minute semi-structured interview. An interview protocol was developed to provide comparable data across the interviews[7]. These interviews were transcribed in their entirety.

Data Analysis

At the end of the Technology and Pedagogy I course, all participants completed the ISTE General Preparation Profile for Prospective Teachers Survey. The responses of each participant were entered into an Excel spreadsheet and totals were calculated. These totals were used as one tool for comparing the participants' knowledge of integrating technology into mathematics instruction.

A significant amount of video was collected during this study both during the Technology and Pedagogy I course and the Technology Partnership Project. The analysis of these data followed a modified version of established qualitative methods for video analysis, specifically the *whole-to-part inductive approach* (Erickson, 2006). According this approach, the researcher watched the whole video without stopping and recorded notes as it was watched. Next, the researcher reviewed the video again, and stopped and reviewed parts that seemed significant

[7] See Appendix E for Individual Interview Protocol

to the research questions. Once the significant portions were marked, the researcher transcribed these clips.

Along with videotapes, the audio recordings of the planning meetings were transcribed and analyzed using established qualitative data analysis methods (Erickson, 2006). As with the video data, the audio recordings were analyzed initially following the whole-to-part inductive approach to identify important clips.

The focus of the individual interviews was somewhat different. The primary purpose of the individual interviews was to capture the pre-service teachers' Technology Specific Pedagogy using the psychological perspective. The individual interviews were transcribed in their entirety.

The final set of data consisted of the artifacts collected during Technology and Pedagogy I and during the Technology Partnership Project lessons. For each participant, every assignment and discussion board posting from Technology and Pedagogy I course was collected and copied. During the Technology Partnership Project all lesson plans, teaching documents, and student worksheets were collected as well.

At then end of data collection, case binders were built for each of the five participants. In each participant's binder, all of the available data for that participant was organized in chronological order. The data included (1) printouts of discussion board postings, (2) all assignments from Technology and Pedagogy I, (3) transcripts from courses, planning meetings and interviews, and (4) all lesson plans and teaching documents from the Technology Partnership Project.

The coding and analysis of the case binders included multiple layers of analysis consistent with a modified version of the Qualitative Hypothesis-Generating process outlined by Auerbach and Sliverstein (2003). In their work, the authors describe a way of analyzing data that begins with identifying *relevant text*. Relevant Text is defined as "…passages of your transcript that express a distinct idea related to your research ideas" (p. 46). The next step in the process involves organizing this text into *repeating ideas*, or ideas that appear in the text from two or more sources. Third, these repeating ideas are combined into *themes*, and then the research builds a *theoretical construct* from the themes (Auerbach & Silverstein, 2003).

For this study, each participant binder was reviewed multiple times to identify all relevant text. Some relevant text consisted of single statements from artifacts or teaching episodes, while other relevant text included conversations among multiple participants during course discussions and planning meetings. Table 3.3 displays examples of relevant text from one participant's data[8].

Table 3.3: Examples of Relevant Text

Date	**Research Context**	**Source File**	**Relevant Text**
9/28/2007	Discussion Board	Amy_Motion.pdf	We finally got our computer working correctly and I felt like we were just playing around.
9/28/2007	Discussion Board	Amy_Motion.pdf	Personally I would have preferred someone to tell me exactly what I was looking for, instead of us playing around and guessing what the instructors want us to get out of it.

All of the relevant text for each participant was organized into a master list in an Excel spreadsheet. Each bit of relevant text was cross-referenced with the research context (e.g. discussion board, interview transcript, teaching episode), a hyperlink to the actual source file, and to the date. All relevant text was organized chronologically to aid in the identification of patterns of development over time.

The master list of relevant text was then used to identify repeating ideas. These ideas were used as codes for sorting all of the relevant text. Examples of repeating ideas included: Worksheet Design, Knowledge of Materials, Doing Math by Hand, and Motivation. Table 3.4 lists four examples of Amy's relevant text that was coded as representing the repeating idea of Worksheet Design.

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[8] All participants were assigned pseudonyms.

Table 3.4: Amy's Relevant Text for Worksheet Design

Repeating Idea	Date	Research Context	Source File	Text
Worksheet Design	9/28/2007	Discussion Board	Amy_Motion.pdf	I prefer the "41 Falling Foil" format better than the "40 Falling Objects" format. The "Falling Foil" format lends to better inquiry and leading students through the step by step process. Whereas the "Falling Objects" format is more of an old style lab where you do the activity then analyze and answer questions at the end.
Worksheet Design	2/13/2008	Teaching	CD2A_GAJ_02_13.doc	So, the plan today is, we are each going to give you a little handout that kind of steps you through what to do to make graphs, put your information in and such. And you are going to follow this, and it tells you at the very end, it has questions along the way.
Worksheet Design	2/13/2008	Lesson Plan	GAJ_Lesson3_WS1.doc	3. In cell B10, enter the following formula: = SUM(B3:B9) This formula will add the numbers in all cells from B3 to B9, and the result will be the total weight of our data. Q. What is the total weight of our data? ___________ Q. What formula do you need to put in the cell C10 to get the total volume of the data? ___________ (Put the answer in the cell C10 and complete the data.)
Worksheet Design	2/13/2008	Lesson Plan	GAJ_Lesson4.doc	• Show students the basic functions of excel and making charts. • Give students an objective to "play" with excel and explore. • Give students a worksheet with guiding questions. (that Gary will send to you) • Class discussion of questions.

After all of the relevant text had been organized into repeating ideas, these repeating ideas were organized into themes based on the Learning to Teach with Technology Framework, namely the three parts of Technology Specific Pedagogy. These themes also aligned with the research questions described in Chapter One: The Problem. Figure 3.1 shows how the research questions, the Technology Specific Pedagogy categories, and the data analysis Themes corresponded.

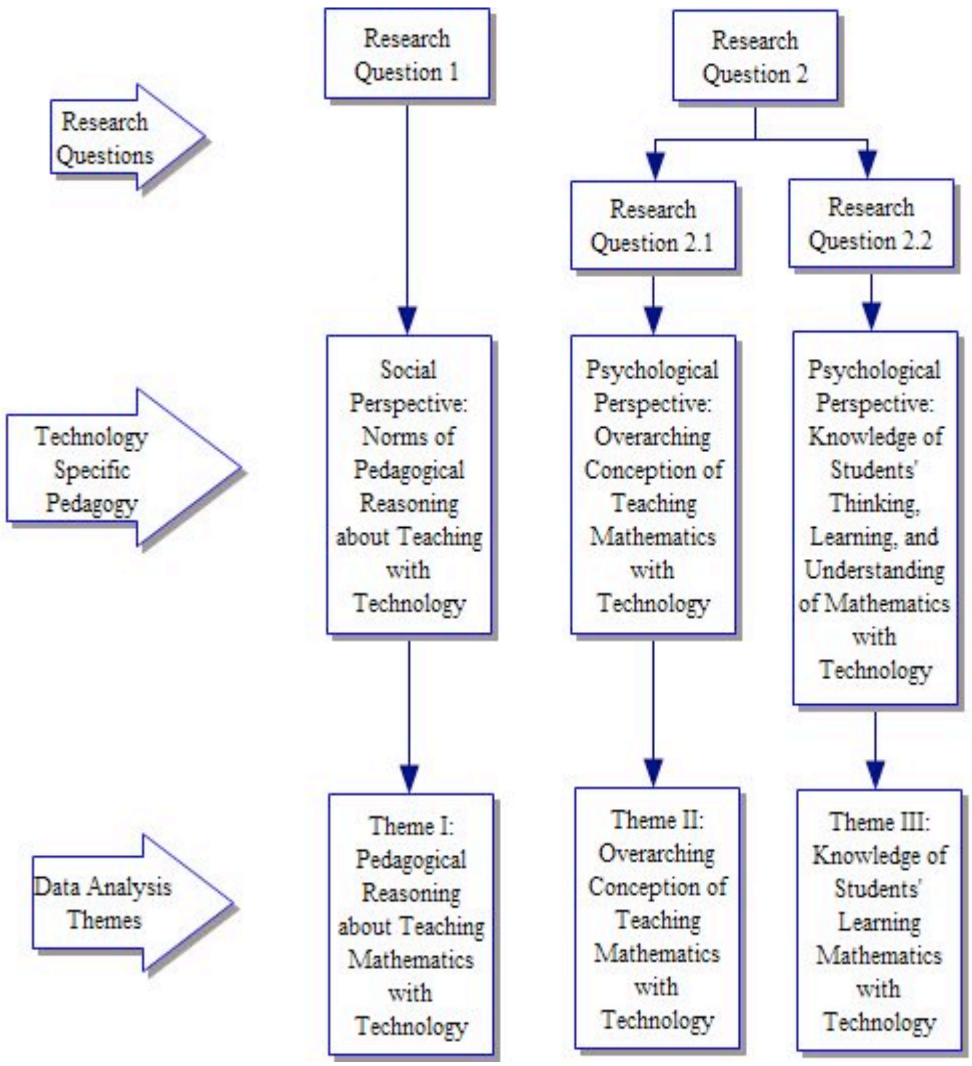

Figure 3.1: Study Design

Repeating ideas that expressed a justification for using technology in the mathematics classroom or for teaching with it in a certain way were grouped in *Theme I: Pedagogical Reasoning about Teaching Mathematics with Technology.*

For example, *Playing to Learn* was classified as Theme I because the pre-service teachers used these ideas to justify the use of open exploration time when learning a new technology tool.

If a repeating idea provided insight into how the pre-service teacher viewed the role of technology in the mathematics classroom, then this idea was categorized as *Theme II: Overarching Conception of Teaching Mathematics with Technology*. For example, the repeating idea of *Doing the Technology* was categorized as Theme II because it demonstrated the pre-service teacher's view that technology should be used in the mathematics classroom for the purpose of developing general skills with the technology in addition to mathematical content objectives.

Finally, if a repeating idea addressed the way that students could learn mathematics by using technology, then it was categorized as *Theme III: Knowledge of Students' Learning Mathematics with Technology*. The repeating idea of *Visualizing with Technology* was seen as representing Theme III since this idea related to how students could learn mathematics by using technology to visualize concepts.

Some repeating ideas addressed themes that were not a focus of this study. For example, one repeating idea, *Knowledge of Materials*, demonstrated the breath of the pre-service teachers' knowledge of available technology tools. This was coded as representing a part of TPCK, knowledge of curriculum and curricular materials. This component of TPCK was a part of the Learning to Teach with Technology Framework, but was not a part of the focus of this study. While this repeating idea gave important insight into the understandings of the pre-service teachers, it was seen as fitting into the third Domain of Professional Expertise, Content Knowledge, and was beyond the scope of this study.

After all of the case binders had been analyzed, an Event Listing Matrix was created from the data of all of the participants (Miles & Huberman, 1994). In this matrix, the ideas of each participant were summarized according to every repeating idea and theme. All of a participant's ideas were summarized as they appeared before, during, and after the Technology Partnership Project. Table 3.5

shows the Event Listing Matrix for three participants (Amy, Heather, and Jesse). This matrix summarizes their ideas about Lesson Design before, during, and after the Technology Partnership Project.

Table 3.5: Event Listing Matrix for Lesson Design

	Lesson Design		
	Before TPP	During TPP	After TPP
Jesse	Some structure good for his own learning	Offered practice activities	n/a
Heather	Need structure; structure leads to learning	Used with worksheet and demonstration	Structure helped her as a teacher; helped ELL students
Amy	Need structure and follow up	Worksheet with structure; follow up instruction	Worksheet was too structured; too restrictive

The purpose of an Event Listing Matrix is to create a valid chronology that characterizes a series of events (Miles & Huberman, 1994). The Event Listing Matrix for each repeating idea was used to identify the changes that had occurred in the pre-service teachers' ideas based on their experiences in the Technology Partnership Project.

There must be data to support both the social and psychological components of what is happening as pre-service teachers learn to teach with technology. In order to capture this learning, repeating ideas must be traced across a number of learning contexts. All assembled, this data set took advantage of qualitative research methods for capturing the learning of the pre-service teachers across a variety of experiences. The result of this analysis is presented in Chapter Four: Results.

CHAPTER FOUR

RESULTS

The purpose of this chapter is to present the results of the study and to connect these results to the research questions outlined in Chapter One: The Problem. The first research question concerned how patterns of participation were displayed across learning contexts as pre-service teachers reason pedagogically about teaching mathematics with technology. The second question focused on identifying the aspects of the Technology Partnership Project that facilitated pre-service mathematics teachers' development of two components of Technology Pedagogical Content Knowledge (TPCK). First, how does the Technology Partnership Project contribute to pre-service teachers' overarching conception of teaching mathematics with technology? Second, how does the Technology Partnership Project contribute to pre-service teachers' knowledge of students' understandings, thinking, and learning in mathematics with technology?

The research questions are directly correlated to the perspectives, both social and psychological, of Technology Specific Pedagogy. This chapter describes the experiences and understandings of three pre-service teachers as they learned to teach mathematics with technology. The results illustrate themes that emerged as the pre-service teachers participated in multiple contexts for learning including: coursework, group planning and field experiences. Each section begins with an overview of the individual participant's background and a description of his or her experiences in the Technology Partnership Project. Repeating ideas that were expressed by the participants across the research contexts were organized into three themes that correlated with the research questions and also the social and psychological perspectives of Technology Specific Pedagogy. The chapter culminates with a discussion of how the ideas that emerged across the cases addressed the research questions.

The Participants

In this chapter, all participants, course instructors, partner in-service teachers, and middle school children have been assigned pseudonyms. The participant selection process for this study was outlined in Chapter Three: Methods. The selection process resulted in five pre-service teachers being chosen for the study: Amy, Jin, Gary, Jesse and Heather. All five pre-service teachers in this study were mathematics education majors enrolled in a graduate program that culminated in a Master's of Science degree in mathematics education and middle and high school mathematics teacher licensure. These participants were selected based on their willingness to participate and their interest in the Technology Partnership Project.

In Chapter Two: Review of the Literature, the importance of a teacher's Professional Identity was described. Professional Identity was defined as the goals, values, commitments, knowledge, and beliefs that a teacher holds. To select participants, the researcher investigated each pre-service teacher's own beliefs about his or her own mathematical and technology expertise. Using the Performance Profile Survey, interview data, and coursework, the five pre-service teachers were categorized according to two characteristics: their background in mathematics and their background with technology. Based on the way that the pre-service teachers described their mathematical and technology knowledge, four of the five were identified as having a strong mathematics background and two of the five were identified as having a strong technology background.

To further distinguish the different participants, the amount of data collected on each one was examined. Variations in the amount of available data for each participant stemmed from how often a person talked in the Technology and Pedagogy course, the number of actual lessons the participant taught, and the number of planning meetings that were accessible to the researcher. Table 4.1 illustrates the summary of the five participants according to mathematics background, technology background, and availability of data.

Table 4.1: Participant Selection Criteria

Pre-service teacher	Mathematics Background	Technology Background	Availability of Data
Amy	Medium	Adequate	Medium
Gary	Strong	Adequate	Medium
Jin	Strong	Strong	Low
Heather	Strong	Adequate	High
Jesse	Strong	Strong	High

Three of the participants were selected for case-study analysis: Amy, Heather, and Jesse. Amy was the only student who described neither a strong mathematics background nor a strong technology background, so her inclusion was important. Both Heather and Gary described a strong mathematics background paired with an adequate technology background. However, the availability of data for Heather led to her selection over Gary. Finally, both Jesse and Jin described a strong mathematics background and strong technology experiences. Jin spoke little during coursework and group planning and Jesse's inclusion as a case allowed for a more complete data set. Altogether, the data from Amy, Heather and Jesse composed a rich picture of the experiences of pre-service teachers learning to teach with technology.

During each phase of data collection, the three case participants were involved in coursework and other experiences outside of the research study. In her interview, Amy described a graduate level geometry course she was taking where they were learning mathematics using Geometer's Sketchpad. Heather and Jesse were both enrolled in a graduate mathematics course where they were designing K-12 mathematics lessons using the TI-Nspire. Because these courses were not taken by the entire cohort of mathematics education majors, the courses were deemed beyond the scope of the research study. All three case participants were also enrolled in a course titled Technology and Pedagogy II. The researcher was not allowed access to this course, so the participation of the pre-service teachers in this context was not included in this study. While not included in the data analysis, the researcher openly acknowledges that the pre-service teachers' learning was impacted by their experiences in these courses.

A complete description of the data analysis process was described in Chapter Three: Methods. In summary, all the data for a particular case were gathered and organized in chronological order. Following a modified version of the Qualitative-Hypothesis Generating Research Method (Auerbach & Silverstein, 2003), the researcher reviewed the data for each case separately. As the data were reviewed, pieces of *Relevant Text* were identified. A master list of *Relevant Text* was compiled for each case. The master list of *Relevant Text* was then organized into groups of *Repeating Ideas*. These *Repeating Ideas* were then categorized according to *Themes.* The *Themes* aligned with the social and psychological perspectives of Technology Specific Pedagogy outlined in Chapter Two: Review of the Literature.

The presentation of the narratives for Amy, Heather, and Jesse follow a specific outline. In each narrative introduction, the participant's mathematical background is described. A brief description of how the participant perceived his or her abilities with technology follows. The introduction ends with a description of the uniqueness of this particular pre-service teacher, such that the case was worthy of inclusion in the results. The remaining portion of the narrative describes the repeating ideas that emerged from that individual's data.

A wide range of data was analyzed to identify repeating ideas from the pre-service teachers' experiences. When a portion of the data is provided as evidence, a citation notation follows. The citation takes the form (Name, Source, Date). For the sake of brevity, data sources have been assigned abbreviations. Table 4.2 illustrates these abbreviations.

Table 4.2: Citation Abbreviations

Data Source	Abbreviation
Transcript from Technology and Pedagogy I	TechPed
Discussion Board Posting	DB
Assignment from Technology and Pedagogy I	Assign
Team Planning Meeting during Technology Partnership Project	Plan
Teaching Observation during Technology Partnership Project	Teach
Lesson Plans during Technology Partnership Project	Lesson
Individual Interview	Interview

Amy

Introduction

In her individual interview, Amy spoke openly of early struggles with mathematics. “We actually talked about this in class earlier. How [the other pre-service teachers] were all told when they were earlier, like younger, that they were good at math, and I was NEVER told I was good at math” (Amy, Interview, 2/27/08). Amy also described herself as a bad test taker and remembers that she was not “tracked” into algebra as an eighth grader with her friends. She commented that the tracking experience had a powerful impact on her perceived abilities and she seemed proud to have overcome those struggles in college. In her undergraduate program, Amy majored in mathematics with a minor in chemistry. However, she displayed a lack of confidence in her mathematical abilities, saying that she was “terrible at mental math” and that she was “…not a person that just gets it. I really worked to get math and to remember math is like a whole different concept. It takes me so much longer to remember it” (Amy, Interview, 2/27/08).

Amy’s experience learning mathematics with technology was limited. In her interview, Amy shared that in high school, she did not use technology in her mathematics classes. In college, the mathematics department barred the use of graphing calculators and her only experience with using graphing calculators in college was in a statistics course. However, she did have the opportunity to work as a teaching assistant in the chemistry department where the use of spreadsheets was required for data analysis and graphing. This experience helped her confidence in teaching with spreadsheets. In the Technology and Pedagogy course, Amy commented that spending class time learning to use Excel was not as useful since, “Most people in the cohort have been using these programs for a long while and feel confident in how to use them” (Amy, DB, 10/25/07).

During the Technology Partnership Project, Amy displayed fluency with the use of the interactive white board during instruction. She had prior experience teaching with interactive whiteboards from her fall student teaching practicum. On two occasions during the Technology Partnership Project, Amy stepped in to encourage her teaching partner, Gary, to use the SmartBoard. In another instance, Amy was able to assist him in troubleshooting a problem with the whiteboard that the partner in-service teacher could not solve (Amy, Teach, 2/19/08).

While she felt confident with some technology tools, Amy displayed some gaps in her knowledge of the materials. Amy’s confidence with spreadsheets was contrasted by some difficulties she had during her teaching. On four occasions, Amy incorrectly told the students and her pre-service teacher partners that it was necessary to double click in a cell before text could be entered (Amy, Teach, 2/13/08). She also told students during whole class instruction that capital letters were necessary for formulas to calculate correctly, even though the software did not require it (Amy, Teach, 2/13/08). Lastly, she contradicted a student who correctly described a process for graphing that included selecting multiple data series when graphing (Amy, Teach, 2/14/08). It was not actually necessary for Amy to know every feature Excel before using it with students. However, these errors pointed to potential gaps in Amy’s knowledge of this particular technology tool, one with which she felt confident using.

During the Technology Partnership Project, Amy was paired with two other mathematics education students: Jin and Gary. Amy’s team worked with an in-service teacher, Carrie Sanders, in a 7th grade general mathematics class. This class had 24 students, five of whom were designated as English Language Learners (ELL) and nine students who qualified for special education services. Ms. Sanders taught her class using a self-designed project based curriculum. Prior to the Technology Partnership Project, the middle school students had completed a project that connected mathematics to the environmental issues. Part of this experience included the completion of a school wide "trash audit" where the children analyzed, sorted, and weighed trash from the school cafeteria trash cans.

In the initial Technology Partnership Project planning meeting, Ms. Sanders suggested that the students could take the data from trash audit and use spreadsheets to analyze the data. Amy agreed with this idea suggesting that "Yeah. Cause you could combine all the data as a whole for the school as well with Excel, just copy and paste" (Amy, Plan, 01/14/08). The team of Amy, Jin, and Gary prepared six lesson plans over seven class periods. During the Technology Partnership Project, brainstorming and planning was completed by the group and each member of the group taught a portion of each lesson each day (Amy, Interview, 2/27/08). Amy typically started the lessons and she led most of the whole group instruction. Ms. Sanders was Amy's cooperating teacher from the fall term student teaching practicum. Because of this, Amy had a unique insight into the classroom culture, Ms. Sanders' teaching style, and the classroom's resources, like the interactive whiteboard.

The unit started with the trash audit. After the trash audit data were collected, the children brainstormed questions that they would like answered from the data. Next, students practiced hand computation of percents in the classroom using calculators and long division algorithms. The trash audit data were used to frame the mathematics exercises with percent calculations. Students then went to the computer lab for two lessons where they used a worksheet to learn how to enter data, calculate sums, and graph the trash audit data with Excel. Amy's group followed this instruction with a class discussion of questions about the graphs that were generated by the computer. The time in the lab was followed by another day in the classroom where the students did more hand calculation of percents and were shown the format for the final project that they would be assigned. On the final day of the unit, students were in the lab using a word processing program, Word, to complete a write-up to answer two student-selected questions from the first day's brainstorming session. The final project submitted by the students was a word-processed document supported by graphs that had been copied and pasted from Excel into Word.

Amy's experiences during the study were unique in that she was the only student in the Technology Partnership Project who did not identify herself as having strong mathematics skills. She also indicated little experience using technology as a learner or in her personal life. She had the lowest score on the General Preparation Profile Survey (46), indicating that her confidence with using technology was low in comparison with her counterparts in the Technology Partnership Project. While Amy's background was unique to this study, she was not unique among teacher candidates in general. Each year, there are pre-service teachers without strong subject matter knowledge or technology knowledge that seek teacher licensure. For these reasons, Amy's experience during this project provided an important contribution to the research.

Theme I: Pedagogical Reasoning about Teaching Mathematics with Technology

Certain repeating ideas appeared during the analysis of the data collected about Amy in the various contexts of the study. First, as Amy reasoned about teaching with technology, the idea of *Playing to Learn* surfaced in her work. *Playing to Learn* was a pedagogical strategy that Amy described as important to her own learning as a student in the Technology and Pedagogy course. She also identified *Playing to Learn* as a useful tool for teaching during the Technology Partnership Project. While she identified drawbacks of *Playing to Learn*, Amy clearly found it to be beneficial for designing lessons that used technology to teach mathematics.

In the Technology and Pedagogy class, the course instructor, Mr. Compton, used open inquiry time as a way for the pre-service teachers to learn to use various software like LoggerPro, Geometer's Sketchpad, and ImageJ. On the day that Geometer's Sketchpad was introduced, the instructor provided a checklist of features of the software and then asked the pre-service teachers to work in pairs to discover as many of these features as they could in the given time. Amy found this strategy of *Playing to Learn* to be useful in her own learning. "Overall I have learned to not be scared of [S]ketchpad and that playing is really the only way to learn it" (Amy, DB, 10/23/07).

Playing to Learn as a student in the Technology and Pedagogy course resulted in Amy reflecting on how this strategy might be useful in her own teaching. She saw *Playing to Learn* as a way for students to have fun, and learn more effectively.

> To introduce [Geometer's Sketchpad and ImageJ] I would let the students go crazy and just explore the program. I think students will have more fun learning and remember more if they discover features of each program by themselves (Amy, DB, 10/23/07).

When Amy began teaching during the Technology Partnership Project, her ideas about *Playing to Learn* were tested in the context of a real classroom. In the unit, the team of Amy, Gary, and Jin designed lessons that included the strategy of *Playing to Learn*. One objective from Lesson Four called for the instructors to "Give students an objective to 'play' with excel (sic) and explore" (Amy, Lesson, 2/14/08). As she taught, Amy openly shared with her students her pedagogical reasoning for using *Playing to Learn*.

> And then, a lot of the class time is going to be just you guys working on whatever you can to figure out as much about Excel. We are not going to baby step through it with me showing you on the projector. Cause I know some of you are way faster, and you need to go at your own pace (Amy, Teach, 2/13/08).

The worksheet that accompanied Lessons Three and Four was designed to lead students through data entry and the creation of a circle graph. At the end of the worksheet, students were asked to "Try to make column chart, bar chart, and line chart of the data" (Amy, Lesson, 2/13/08). The intention of this task was for students to discover how to make these graphs without being told the intermediate steps. This worksheet represented a mix of *Playing to Learn* and step-by-step instruction. After the lesson, Amy reflected on the value of teaching with the worksheet. "Like it is cool for them and they followed the worksheet, but I think it took away a little bit. I know if we would have just let them play with it, I am sure a lot of students could have just done it" (Amy, Interview, 2/27/08).

While Amy seemed committed to the pedagogical choice of *Playing to Learn*, she was also able to identify some drawbacks. As a graduate student, Amy had experienced frustrations as she used technology in a geometry course.

> I can't say that just letting students go with Sketchpad is good to a point, cause I have seriously spent an hour and a half on one question and someone could show me how to do it in two seconds and that was frustrating. So there's definitely that point, it taught me a lot of good stuff for when I am going to teach. There is definitely a point where like you can't just let students go, cause some of them don't know the buttons to push. So you've got to have that instruction there behind it (Amy, Interview, 2/27/07).

Amy spoke in discussion board postings of the need for clear learning objectives and for activities that focused on discovering only small portions of a particular tool's capabilities (Amy, DB, 9/28/07 & 10/23/07). Amy saw a way that students could be frustrated by time dedicated to open inquiry. However, she did not completely cast aside the idea that *Playing to Learn* was beneficial to student learning. Instead she felt it should take place within some kind of structured instruction.

How did Amy visualize *structured instruction*? The answer can be found in the second repeating idea in Amy's work. This idea, *Lesson Design*, was influenced by Amy's experiences as a student in the Technology and Pedagogy course. These experiences surfaced again as she planned and delivered her unit in the Technology Partnership Project.

On the first day of the Technology and Pedagogy course, Mr. Compton asked the pre-service teachers to work through two labs using motion sensors and LoggerPro software. The first lab was called *40 Falling Objects*. The worksheet for this lab followed a traditional format with sections titled objectives, materials, procedure, data, processing the data, and extensions. In contrast, the second worksheet, *41 Falling Foil*, had a different lesson design. The second lab began with discussion and questions to assess students' prior understandings. The worksheet asked the pre-service teachers to complete three trials while collecting data, answering questions, and getting instructor signatures at various checkpoints throughout the activity.

Mr. Compton asked the pre-service teachers to complete the labs in small groups and then to compare and contrast the two ways of designing worksheets. As Amy reflected on the process, she found the *41 Falling Foil* lab to be more aligned with her own preference for learning.

> I prefer the '41 Falling Foil' format better than the '40 Falling Objects' format. The 'Falling Foil' format lends to better inquiry and leading students through the step by step process. Whereas the 'Falling Objects' format is more of an old style lab where you do the activity then analyze and answer questions at the end (Amy, DB, 9/28/07).

She went on to reflect that she disliked answering all of the questions at the end of the *40 Falling Objects* worksheet and that she preferred to answer the questions as she went along, as in the *41 Falling Foil* worksheet.

This preferred type of *Lesson Design* surfaced again as Amy planned and delivered the lessons during the Technology Partnership Project. The team lesson plans called for a worksheet that included "guiding questions" just as they had seen in the *41 Falling Foil* worksheet (Amy, Lesson, 2/13/08). The actual look of the worksheet that Amy used in her teaching was similar to the example that had been used in the Technology and Pedagogy class. Both worksheets included student tasks followed by questions to check understanding. Table 4.3 shows portions from each worksheet compared side by side.

Table 4.3: Comparison of 41 Falling Foil Worksheet to Analyze the Data with Excel Worksheet

***41 Falling Foil* Worksheet** Technology and Pedagogy Course 9/26/07	***Analyze the Data with Excel* Worksheet** Technology Partnership Project Lesson 3 2/13/08
Trial 2 For this trial you should fold your original piece of foil in half and then bend the edges up slightly (Still think cookie sheet, only it's half as big). **Q13.** Has the **mass** and/or **weight** of your foil changed as a result of this folding? ___________________________________ **Q14.** What **has** changed as a result of this folding? ___________________________________	In cell B10, enter the following formula: = SUM(B3:B9). This formula will add the numbers in all cells from B3 to B9, and the result will be the total weight of our data. Q. What is the total weight of our data? ___________ Q. What formula do you need to put in the cell C10 to get the total volume of the data? ___________

When reflecting on the two contrasting motion sensor labs, Amy shared that if she were to use these labs as an instructor, she would include a "quick review" or even a "follow-up day" (Amy, DB 9/28/07). Later in the Technology and Pedagogy course, the pre-service teachers learned to use Geometer's Sketchpad. During this lesson the instructor concluded the initial open exploration time with a short summary of key features that the pre-service teachers needed to start the next activity. Amy found this summary useful for her own learning. "I thought the process of letting us discover things with the program worked very well, especially when she summed up what we would needed (sic) to know to do the assignment" (Amy, DB, 10/23/07).

When Amy began teaching in the Technology Partnership Project, her team implemented lesson objectives that included a *Lesson Design* with open-ended inquiry followed by a structured summary discussion (Amy, Lesson, 2/13/07). After students completed the worksheet, Amy led a short demonstration on what she felt were important features of the software that all students should know. Amy explained her reasoning for this whole group instruction to the class. "Now what we are going to do is we are going to look up at the screen and I am going to go over some key things I want to make sure everyone understands" (Amy, Teach, 2/14/08). She felt it was important to conclude the open inquiry time with some sort of structured summary.

As Amy reasoned about teaching with technology, she balanced the ideas of *Playing to Learn* and *Lesson Design*. The structure of the *Analyze the Data with Excel* worksheet that Amy used in her teaching seemed to conflict with the idea of *Playing to Learn*. However, a closer look at Amy's ideas revealed that she felt that *Lesson Design* provided important structural support as students had open-ended time to explore technology tools. *Playing to Learn* and *Lesson Design* interacted as they played out in her learning and the opportunity to apply them to her teaching caused her to re-think their effectiveness. After the Technology Partnership Project ended, Amy reflected that she was undecided about the effectiveness of her group's pedagogical choices. In her individual interview, the researcher probed this thinking.

> Amy: I don't really think the students really got the idea of the wonderfulness of Excel and like what it can do. Like it is cool for them and they followed the worksheet, but I think it took away a little bit.
>
> Researcher: Do you think that was because of the worksheet and that it kind of led them down a path? Or?
>
> Amy: I don't know. Maybe. Maybe it was. I know if we would have just let them play with it, I am sure a lot of students could have just done it. Then there is also the students that would have sat there and been like, "There's no button to push on here, I am mean really. These ten buttons on the top, they don't do anything." (laughs). But, so….
>
> Researcher: There are different ways of thinking about it.
>
> Amy: Yeah, so I can't--I don't know if the worksheet was good or bad (Amy, Interview, 2/27/08).

The Technology Partnership Project allowed Amy to test her ideas about *Lesson Design* and *Playing to Learn* in the context of a real classroom. In reflecting on this teaching experience, Amy seemed to be in flux about the way that these two themes impacted student learning. She recognized that while some students benefited from the structure of the worksheet in the *Lesson Design*, she also imagined other students whose needs were not met by this structure and benefited more by *Playing to Learn*.

Theme II: Overarching Conception of Teaching Mathematics with Technology

Throughout the various contexts of the study, Amy expressed ideas that indicated her general sense of what it meant to teach mathematics with technology. The first repeating idea, *Technology as an Extension*, was strongly tied to her own experiences as a learner. Initially, Amy felt that students should be able to do all of mathematical processes by hand and that technology should play a role as extending learning rather than as a tool for learning. However, after her experience in the Technology Partnership Project, her stance on *Technology as an Extension* became more tentative.

In high school and in college, Amy was required to do all graphing in her mathematics courses without the aid of a calculator or computer (Amy, Interview, 2/27/08). She felt that this experience gave her an advantage over the other pre-service teachers who used calculators for graphing in their mathematics classes because if you could do mathematics by hand, "…you understand it a lot better" (Amy, interview, 2/27/08). Specifically, Amy pointed to polar coordinates as one example.

> I didn't get to graph polar coordinates by hand for my whole first year. And like I know polar coordinates way better than anyone like here. Because they're just like, "Oh yeah, you type in this thing and you get em." And I am like, "You gotta draw the lines, and the points, and it takes like forever!" (Amy, Interview, 2/27/08).

In the Technology and Pedagogy course, Mr. Compton gave the pre-service teachers a graphing assignment and allowed the students the option of graphing with Excel or graphing by hand. Amy chose to submit a handmade graph (Amy, Assign, 10/14/07). After this assignment was completed, Mr. Compton asked the students to break into small groups and discuss the question, “What is the best way to teach graphing: By hand or by computer?” Amy spoke openly in her group about the importance of graphing by hand.

> Amy: (Reading from the slide on overhead) What is the best way to teach graphing?
>
> Jackie: It depends on the level. I would say by hand.
>
> Gary: I think so too.
>
> Amy: Teach graphing…the best way to teach graphing? I think by hand.
>
> Jesse: I think so, get them started.
>
> Amy: You do the physical like this and this, this and this (Moves hand through the air as if plotting points). You have to label them which helps you remember them better.
>
> Gary: It kind of takes away the mystery of where…
>
> Amy: Yeah.
>
> Gary: …if you just type it into a spreadsheet and it graphs.
>
> Amy: And it pops up and you are like, “Oh, my gosh!” (Amy, TechPed, 10/17/07).

Amy’s ideas about the importance of doing mathematics by hand extended into her teaching during the Technology Partnership Project. The final assignment in the unit asked students to create a Word document that answered questions about the trash audit data. In this document, students were instructed to include computer-generated graphs to support their conclusions. However, all percentage calculations were to be done by hand on the back of the printed sheet (Amy, Lesson, 2/12/08). Amy’s group felt it was important that students could demonstrate these calculations without the use of the computer.

After teaching in the Technology Partnership Project, Amy’s stance on *Technology as an Extension* remained, but became more tentative. In her interview, she shared the idea that “[Technology] is just like the extending factor on the basics you learn" (Amy, Interview, 2/27/08). However, her reflection of how the students learned with the technology tool caused her to see some potential benefits to using technology as a way to learn mathematics, rather than just to extend the ideas. She shared that by allowing the students to use the technology for computations, they were able to access much bigger mathematical ideas without being caught up in the calculations.

> I think it helped improve it by them not having to know the specifics of calculating the percentages. So they could see percentages as a whole, like all the percentages make up a whole. And they could relate it like to higher topics. Like they came up with their own questions and then answered them. So that really helped. Because I know a lot of the students could answer all those questions, but still have no idea how to calculate percentages. So it gave them that bigger idea, without computational, like, frustrations (Amy, Interview, 2/27/08).

After instruction, Amy described Excel as enabling students to create representations of fractions, percentages, and decimals that would allow students to notice features of the mathematics beyond just the algorithm. The theme of *Technology as an Extension* seemed to stay somewhat consistent throughout Amy's experience, but the Technology Partnership Project allowed Amy to visualize other possible uses for technology in the mathematics class.

A second repeating idea was seen in Amy's work and provided additional insight into her general sense of what it meant to teach mathematics with technology. This idea, *Technology as a Simplifier*, surfaced somewhat in Amy's coursework, but was prevalent in her instruction during the Technology Partnership Project. Amy described *Technology as a Simplifier* as justification for learning to use technology. However, her ideas indicated conflicting evidence as to how this simplification impacted student learning.

In the Technology and Pedagogy course, Amy reflected on Geometer's Sketchpad and ImageJ software and their potential for classroom use. She offered the idea of *Technology as a Simplifier* as justification for including these software packages into mathematics and science instruction. "Life is so much easier with graphing programs all students should learn how to use them for math and science" (Amy, DB, 10/14/07).

When Amy was teaching during the Technology Partnership Project, she described her view of Excel to the students.

> So the point of Excel is that you don't have to use your brain. Like, it is supposed to do the math for you. So type this in and see if you get the same answer. You type this formula, to make it do that. You don't have to do it (Amy, Teach, 2/13/08).

Here, Amy described the software as doing more than just "making life easier." She viewed the tool as a way for students to stop thinking. Later, Amy talked with the students about why they were spending class time learning to use this program. "The goal of the computer, this is why we use this, is that we don't want to think in our head and do the math. We want to make the computer do the math" (Amy, Teach, 2/14/08). Amy spoke with the students individually describing the way that the software simplified computation as the "joy of using Excel" and as "magic" (Amy, Teach, 2/13/08 & 2/14/08).

Simply examining Amy's teaching suggested that the theme of *Technology as a Simplifier* was a drawback to student learning since she described it as a way for students to stop thinking. However, when Amy reflected on her teaching after the Technology Partnership Project, she expressed ideas that the ability of technology to make things easier might actually facilitate student thinking. She described the graphing capabilities of Excel as allowing students to answer questions from data, rather than just making calculations from it.

> I think it would be a lot like, the representations of it would be frustrating, because to do like real pie graphs, like you have to measure, like and convert, and that would be frustrating for a lot of students. That is really why we have Excel for pie charts, so you don't have to measure and do that…. So it gave them that bigger idea, without computational, like, frustrations. That helps (Amy, Interview, 2/27/08).

The idea that *Technology as a Simplifier* allowed students access to more mathematics continued to influence Amy as she prepared for her full time student teaching practicum.

> Like, I am working on my technology sequence for exponents right now, and for students to look at data and come up with an equation. Just, NO! I can't even do that! (laughs). It's just too much work! So technology you can get past the tedious, find the equation, and just have it and then you can talk about trends and everything (Amy, Interview, 2/27/08).

Beyond allowing access to higher order mathematical thinking, Amy saw *Technology as a Simplifier* as enabling students to create more accurate representations of data. She felt that some big ideas just took "too much time by hand" and it was unreasonable to ask students to analyze large data sets without technology to make it easier (Amy, Interview, 2/27/08). As Amy moved through various research contexts, she spoke differently about the repeating idea of *Technology as a Simplifier*. Her ideas demonstrated *Technology as a Simplifier* benefit and a drawback to student learning. When reflecting on her experience after the Technology Partnership Project, Amy's ideas appeared to move toward thinking about how to use *Technology as a Simplifier* to enhance instruction.

A third repeating idea emerged from Amy's experiences giving additional insight into her general sense of teaching mathematics with technology. This idea, *Doing the Technology*, indicated how Amy viewed the technology-infused lessons. Was she teaching the technology in a mathematics class, or was she teaching mathematics using technology? The idea of *Doing the Technology* first emerged as Amy taught during the Technology Partnership Project. Later, this idea surfaced again as she reflected on her teaching.

On the first day in the computer lab during the Technology Partnership Project, Amy introduced the day's activities emphasizing that students would be learning to use Excel. "Okay, so, today, as we told you before, we are going to be doing Excel, like I promised" (Amy, Teach, 2/13/08). In this introduction, the mathematical ideas that would be explored using the technology were not mentioned. Instead, she told the students to spend class time "…working on whatever you can to figure out as much about Excel" (Amy, Teach, 2/13/08).

On the second day in the computer lab, Amy spent time reviewing the worksheet with the whole class. She explained the purpose of the review was

"…to make sure that everyone really understands so that we are all wrapped together and knowing Excel" (Amy, Teach 2/14/08). This review ended with Amy asking, "Any questions at all? Does everyone think they got it? They understand Excel?" (Amy, Teach, 2/14/08). As Amy reviewed the concepts and solicited questions, the focus of her instruction was on students "doing" Excel, i.e. *Doing the Technology*. Amy presented this instruction in a way that was disjoint from the mathematics and the content objectives that her group had originally planned.

Later, Amy reflected on her experiences in the Technology Partnership Project. In this reflection, her focus remained on how well the students had learned the technology, and did not emphasize the mathematics. When asked how the pre-service teachers had decided what to teach, when to teach, and how to teach it, Amy shared that their planning had focused on what they wanted the students to "do on Excel" and she did not mention the mathematics that the students needed to know (Amy, Interview, 2/27/08). In their teaching, Amy's group mixed classroom instruction with computer lab time. This mix was dictated by access to the computer lab, rather than due to pedagogical decisions of the group (Amy, Interview, 2/27/08). The controlling focus of the unit was *Doing the Technology* and was seen in both the planning and execution of the lessons.

During the initial planning meeting, Ms. Sanders indicated that the primary objective for the unit should be continued work with fractions and an introduction to percents (Amy, Plan, 1/14/08). As instruction was carried out, these mathematical objectives were given lower priority and objectives related to *Doing the Technology* took hold. When asked what the students had learned during the unit, Amy reflected a frustration about the students' learning about the technology. "I don't really think the students really got the idea that the wonderfulness of Excel and like what it can do" (Amy, Interview, 2/27/08). It was important to Amy that the students learned to use Excel, and *Doing the Technology* was a primary goal of the instruction.

Amy's general sense of teaching mathematics with technology changed as she participated in the various research contexts. Overall, Amy's ideas indicated a view that technology should be used as an extension after mathematics was mastered by hand and that it should be used to simplify mathematical computations. However, in her final reflection, Amy could imagine how *Technology as a Simplifier* could enhance instruction. Her teaching focused on students learning to use the technology as a goal separate from the other mathematical content objectives. As she reflected on this focus after the project ended, Amy's shared dissatisfaction with this focus, and she appeared to question the benefits of *Doing the Technology*.

Theme III: Knowledge of Students' Learning in Mathematics with Technology

Many of the ideas that surfaced in Amy's work were strongly influenced by her own experiences as a learner. These experiences helped Amy develop ideas about how students learned with technology. Two repeating ideas were identified that related to how students thought and learned as they used technology. The first, *Visualizing with Technology*, addressed how students used technology to help them understand graphical representations of mathematical concepts. Amy's experiences learning with Geometer's Sketchpad and with Excel helped her to think about ways that students' learning would be enhanced with these tools.

In the Technology and Pedagogy course, Amy did an activity where she collected data on the dimensions, weight, and volume of a toy "Grow Creature." Using this data, the pre-service teachers created graphs and analyzed the results. When Amy reflected on the activity, she found value in teaching graphing through an activity, and commented that Excel might be a good tool for extending the graphing activity after it had been completed by hand (Amy, DB, 10/14/08). As previously discussed, Amy placed importance on creating graphical representations by hand before moving to computer-generated graphs. However, during the Technology Partnership Project, Amy's group did not have the students create representations by hand. All graphs were done using the computer. The idea of doing all the graphs in Excel was first presented by Ms. Sanders in the initial planning meeting (Amy, Plan, 1/14/08). This suggestion was accepted by the group and the lessons were planned accordingly.

When Amy reflected on the Technology Partnership Project, she shared that the technology gave the students "a way to represent [percentages] using technology," "look at what they can notice using the technology," and "see percentages as a whole" (Amy, Interview, 2/27/08). Amy was able to identify *Visualizing with Technology* as one way that students' thinking and learning could be enhanced through the use of appropriate technology.

Another aspect to the repeating idea of *Visualizing with Technology* developed when Amy spoke of geometry, both in her own learning and in her teaching. Before the Technology and Pedagogy course, Amy's experience using Geometer's Sketchpad was limited. During the class, the pre-service teachers did an investigation of the Golden Ratio using images imported into the software. Amy shared that she learned a lot in this activity including how to measure and calculate distances. She found it interesting that the software adjusted these calculations as the figure was changed (Amy, DB, 10/23/08). She thought this might be a useful way for students to learn other geometry concepts including polygon properties.

> I could even use this program when teaching middle school students different types of triangles (right, acute, obtuse). They could construct a triangle and move one point around and discover how it changes the type of triangle in relation to its angles. This activity would be easily done with the calculate function. A student could calculate one angle and then when moving the points around the measurements would change (Amy, DB, 10/23/08).

During the Technology Partnership Project, Amy was taking a college geometry course that used Geometer's Sketchpad to explore and develop geometric concepts. As a learner, Amy found the dynamic nature of the technology-based representations to be a useful tool for understanding concepts with triangles. "Just being able to like move it around and like see it. Because it is really hard to redraw a triangle and measure every time" (Amy, Interview, 2/27/08). She also was able to imagine how *Visualizing with Technology* allowed students to better understand mathematics.

> And doing just like, when you have two parallel lines and doing the like the transversal and all those. Like if you move em around

> you can actually see it. Instead of just listening to your teacher and be like, "I am sure she is right with that." So it is more of a hands on, you can discover it with geometry, which I really like--really wish I would have had (Amy, Interview, 2/27/08).

Creating graphical representations of mathematical concepts is an important component of any mathematics curriculum. Amy's ideas showed that she was beginning to notice how technology might allow students to *Visualize with Technology* while they learned new concepts.

In addition to visualizing, Amy's shared another repeating idea related to students' learning with technology. This idea, *Motivation*, addressed the attitudes and dispositions that students had towards learning with technology. While present in Amy's ideas, *Motivation* was not as common in the data as some of the repeating ideas that were previously described.

Amy had little experience as a learner using technology in the mathematics classroom. Clearly her own motivation to learn the subject did not come from the presence of technology tools. She spoke of a general dislike of geometry as a subject in high school and that she had few memories of what they actually studied (Amy, Interview, 2/27/08). In that same interview she commented that Geometer's Sketchpad made geometry more hands-on and discovery-based and that she really wished she had been taught that way. While the *Motivation* factor of technology had not been essential to her own learning, she imagined that it could have played a role in her own learning of mathematics.

During her teaching, Amy used words like "magic" and "joy" to describe what Excel did (Amy, Teach, 2/13/08 & 2/14/08). It was clear that she tried to convey a message to the students that the software was exciting and fun. As reported in the previous section, Amy described Excel as software that would do the mathematics for the students so they did not have to use their brains. Ms. Sanders' class consisted mostly of children who had not been successful in mathematics in the past. Possibly, Amy felt that by describing the software in this way, students would be more motivated to use the software as a learning tool.

After the Technology Partnership Project, Amy reflected on the impact the technology had on students' learning. She commented that learning with technology added a "cool factor" for children (Amy, Interview, 2/27/08). When asked how their learning would have been different if the technology had not been used, she responded, "I don't think it would be as much fun! Definitely every time technology is in there, it's fun!" Amy saw from her own experiences that learning with technology was an attraction for students. She incorporated this repeating idea of *Motivation* into her teaching and saw that it was an important part of what the students had accomplished during the unit.

Amy's knowledge of students' learning in mathematics with technology focused on two areas. She shared ideas about how technology facilitated visual representations, citing examples from her own learning. She was also able to identify ways that *Visualizing with Technology* might help students to better understand certain mathematical concepts. The excitement of using technology had not been a contributing factor in Amy's own learning. However, she shared ideas about *Motivation* in her teaching and reflections, and identified this idea as an important factor that could influence learning.

Heather

Introduction

In her interview, Heather described her K-12 mathematics experience as "traditional" and indicated that she only began to enjoy mathematics during her junior year in high school (Heather, Interview, 2/21/08). That year, Heather had a mathematics teacher who took a special interest in her and this relationship changed the way Heather thought about the subject. "He taught me about chaos theory and the Fibonacci sequence, like stuff that I had never even heard of before. And like, he showed me all the NOVA programs so I just really got into [mathematics]" (Heather, Interview, 2/21/08). This same teacher nominated Heather for a mathematics competition where she took first place. This experience influenced her decision to major in mathematics once she went to college. In college, Heather found that the mathematics courses were "better, more interactive" (Heather, Interview, 2/21/08). Yet she still felt that the mathematics teaching she experienced as a learner did not match the style advocated by the licensure program. "But now being in this program and I am learning how math like is better taught, it's very new to me. Never experienced it before" (Heather, Interview, 2/21/08).

Heather's background using technology was limited. Unlike her friends at school, Heather's family did not have a computer at home when she was in high school. She looked forward to going to school so that she could access the Internet (Heather, Plan, 2/05/08). Although her high school provided Internet access, Heather did not use technology in any of her mathematics classes. In college, Heather's mathematics classes did not use technology, but she did take a computer programming class as part of her degree requirements. In her last year of college, she took a course called Technology Foundations for Teaching Math and Science as a prerequisite to the teacher licensure program. This course was her first formal instruction related to using technology personally or in teaching (Heather, Interview, 2/21/08).

While her background with technology was limited, Heather was motivated to learn to use technology in both her personal life and in her teaching. Heather's technology skills were mostly self-taught and she felt she had learned a lot from just being required to use it in college. "Like I kind of pride myself with being able to figure stuff out on the computer if something goes wrong" (Heather, Interview, 2/21/08). In reflecting on her experiences in the Technology and Pedagogy course, she shared that "I enjoyed all of the activities that were chosen and I am excited to learn more about each of the programs next term" (Heather, Assign, 10/24/07).

During a group discussion in the Technology and Pedagogy course, Heather shared her experience using classroom remote response systems, but described how she had not an opportunity to use an interactive whiteboard and was hoping to use one soon (Heather, TechPed, 9/26/07). In the Technology Partnership Project, Heather's classroom had an interactive whiteboard that was permanently mounted at the front of the room. She used this tool skillfully in her instruction, but recognized that there were probably gaps in her knowledge. "The stuff that I know how to do so far [with the SmartBoard] has been pretty easy to figure out. I think, its capabilities--I think I don't know everything. I know I don't know everything" (Heather, Plan, 1/14/08).

For the Technology Partnership Project, Heather worked in a group with two other pre-service teachers: Jesse and Linda. Like Heather, Jesse was working toward a Master of Science degree in mathematics education. Linda, however, was working toward a degree in science education. Heather, Jesse, and Linda taught with Ms. Thomas in a 7th grade general mathematics class with 33 students. In this class, 12 students were designated as English Language Learners, and 20 were enrolled in a remedial reading class. Prior to the start of the Technology Partnership Project, this class had been reviewing two-digit multiplication problems, where the instruction focused primarily on mastery of algorithms for this process.

During the initial planning meeting, Ms. Thomas described the students' mathematics skills.

> There are kids that don't know their facts. They can't do two minutes worth of times tables of less than sevens. And then there are kids that know through their twelves and can do those really fast (Heather, Plan, 1/14/08).

Ms. Thomas asked that the pre-service teachers plan a project-based unit to help students connect concepts of factions, decimals, and percents. Heather suggested that one potential idea would be to have the students create a survey to be administered to other students. These data could be used as a source for exploring concepts of fractions, decimals, and percents (Heather, Plan, 1/14/08). While Ms. Thomas was unsure of how technology could be used to complete this activity, she was amenable to the pre-service teachers' ideas and allowed them total access to her classroom for 11 class periods.

The unit began with an introduction to the project. The students were told that they were to create a survey, collect data, and use Excel to "organize and analyze the results" (Heather, Lesson, 1/16/08). The students were also told they would create a final product, but that they could use poster board, PowerPoint, or video to display the results. The next two lessons in the unit were dedicated to designing the surveys and collecting data. On the fourth and fifth day, students did a "practice run on Excel" with the sample data provided by the pre-service teachers (Heather, Lesson, 1/29/08). On day six, Heather did a short demonstration on formatting data in Excel and then students began working in their groups. The remainder of the unit was spent on small group work time. Heather, Jesse, Linda, and Ms. Thomas moved throughout the room working with individual groups on their graphs, posters, PowerPoint presentations, and videos. During these lessons, whole group instruction was typically limited to short announcements at the beginning of class and never lasted more than a few minutes.

Heather's participation in the Technology Partnership Project offered insight into the experiences of a pre-service teacher with a strong mathematical background accompanied by little formal technology instruction. On the General Preparation Profile survey, Heather's score was 58, the second lowest of the participant group (Heather, Survey, 10/24/07). In spite of this apparent lack of confidence, Heather had a strong intrinsic drive to learn more about technology as evidenced by her interview comments and the speed with which she taught herself to use the interactive whiteboard. Many people consider themselves to be self-taught technology users, so Heather's ideas were an important contribution to the research. For this reason, Heather's ideas were explored in depth.

Theme I: Pedagogical Reasoning about Teaching Mathematics with Technology

As Heather reasoned about teaching with technology, three repeating ideas developed in her work. The first, *Playing to Learn*, was also seen in Amy's ideas, but Heather conceived of it somewhat differently. Initially, Heather was skeptical of the pedagogical choice of allowing students open exploration with technology and she identified a number of drawbacks to this technique. However, during the Technology Partnership Project, Heather used *Playing to Learn* as a strategy in her own teaching. *Playing to Learn* also seemed to be the strategy she found most effective as she reflected on her own learning.

On the first day of the Technology and Pedagogy course, Mr. Compton had Heather's small group learn to use motion sensors through three different open inquiry explorations. In her reflection of the activity, Heather described her group's experience as well as her own experience as a learner. "We played around with movement trying to figure out what each of the graphs represented, but I personally got distracted quickly and was a little confused about what I was supposed to be doing" (Heather, DB, 9/27/07). Heather suggested that while she liked "being able to play around with the motion detectors before formal instruction," she felt the lesson would have been better if had been set up as a "guided inquiry assignment" (Heather, DB, 9/27/07).

Later, Heather experienced more open exploration time with Geometer's Sketchpad. In this lesson, the open exploration was followed by a short summary of important skills. After this lesson, Heather seemed more open to the idea of *Playing to Learn* saying that, "I think that it's important to give students time to explore the program inside (sic) of just reciting directions to them and trying to keep them all on track" (Heather, DB, 10/26/07). Heather's reflections indicated that she was still undecided about the value of open exploration when teaching with technology.

In the Technology Partnership Project, Heather's group taught a lesson where the students were provided with data and given an activity, the *Mini Golf Graphing Challenge* (Heather, Lesson, 2/5/07). In this lesson, students were given cursory instruction on using the graphing features of Excel and then were challenged to discover how to make additional graphs on their own. The students were also instructed to try to determine how to change the graph's font sizes and colors. As Heather worked with a small group, her instruction encouraged the students to *Play to Learn*.

> And this is called the Chart Wizard, and if you click on that. Yeah. It will give you choices about which kind of graph you want to make. (The student asks Heather which kind of graph she should make). Ah, you can pick. You can just play around with each one. You can change the colors it comes up with and stuff like that. Okay? (Heather, Teach, 2/4/08)

With another small group, Heather instructed, "And now you can play with it. You can pick the kind of graph that you want. You can pick the title and stuff like that. You can just play around with it. Okay?" (Heather, Teach, 2/4/08). Prior to the Technology Partnership Project, Heather had demonstrated mixed ideas about the value of *Playing to Learn* when teaching with technology. However, during her instruction, she used it to teach students how to graph with spreadsheets.

When she reflected on her own learning with technology, Heather described *Playing to Learn* as a strategy that she readily used. She shared that, "I am able to look at new software and kind of figure out how it works. But I don't really know how that happened. It is just trial and error I guess" (Heather, Interview, 2/21/08). Taken as a whole, the data indicated that Heather felt *Playing to Learn* was a useful strategy for her own learning and for the learning of children as well.

Like Amy, *Lesson Design* was a second repeating idea that emerged as Heather reasoned about teaching with technology. For Heather, *Lesson Design* was expressed by her ideas when she talked about designing worksheets and designing whole group instruction. Heather's view of an effective design of a worksheet was first shared in the Technology and Pedagogy course and later developed as she taught in the Technology Partnership Project. The Technology Partnership Project gave Heather an opportunity to try out the ideas that she had formed during coursework and planning.

In the Technology and Pedagogy course, Heather's group explored the motion sensors and created a number of different graphs (Heather, TechPed, 9/27/07). In her reflection of this activity, Heather shared that the instructions from the *40 Falling Objects* worksheet and the *41 Falling Foil* worksheet had facilitated her learning.

> For example, Amber was able to create a beautiful sinusoidal wave by bouncing underneath the motion detector. I don't think we would've been able to create this with just the inquiry instructions. We needed the lab instructions to figure out what the power of the motion detector was before we could successfully experiment on our own (Heather, DB, 9/27/07).

In her own learning, Heather seemed to value the presence of some kind of structure as she openly explored new technology tools. Later, Heather commented that this type of *Lesson Design* would be useful for other technology like Geometer's Sketchpad. “Even if you had a set of skills in mind that you want your students to learn, you could include a handout with a checklist of skills like [the instructor] suggested, and then still give them free reign” (Heather, DB, 10/26/07).

During the Technology Partnership Project, Heather had an opportunity to engage in a *Lesson Design* that combined open exploration with some structural support. Instead of a worksheet, Heather suggested during team planning that a short demonstration at the beginning might be more effective.

Heather: Well, I was thinking, and maybe I could just do like a demonstration instead of a worksheet? Cause I think we are crunched on time. So maybe if I just did it on my own.

Jesse: Do you want them to be like following along with you for it?

Linda: That would be really good.

Jesse: Or want them just to be watching?

Heather: I am worried about if they follow along, that they won't really be following along.

Jesse: Yeah (Heather laughs).

Linda: Yeah, but there will be...there will be some that...well are you going to write up the steps? Or, are you just going to show them?

Heather: I am just going to show them...is what I am thinking. I mean.

Linda: So when they do it, then they will ask us and it will be sort of familiar but they may not...

Heather: That is kind of what I was thinking (Heather, Plan, 2/5/08).

Heather agreed that the demonstration would not teach the students everything that they needed and she even admitted that she did not expect students to follow along with her step-by-step. However, she argued that a short demonstration would give students a general sense of what the software could do before open exploration should begin.

Another aspect of *Lesson Design* that can be seen in Heather's ideas related to the way she felt worksheets should be structured. Like Amy, Heather saw value in building worksheets that included questions that were interspersed throughout the activity. She felt that the *41 Falling Foil* worksheet was more "student friendly" and argued that it was more conducive to student learning. "Also, all of the questions were at the end of the lab. I think that after the students had worked through the entire lab, it would be hard for them to think back to what they had observed at the beginning" (Heather, Motion, 9/27/07).

During the Technology Partnership Project, Heather interspersed questions in her own worksheet on the day her team introduced data entry and calculations with the *Practice Using Excel* worksheet (Heather, Lesson, 2/29/08). Table 4.4 shows a side-by-side comparison of the *41 Falling Foil* design and the worksheet Heather's group used. In column one, the *41 Falling Foil* worksheet asks students to complete a task, and then follows this task with short questions to check for understanding. In column two, the *Practice Using Excel* worksheet has the same design, checking for understanding after each task.

Table 4.4. Comparison of 41 Falling Foil Worksheet to Practice Using Excel Worksheet

***41 Falling Foil* Worksheet** Technology and Pedagogy 9/26/07	***Practice Using Excel* Worksheet** Lesson 4 1/29/08
Trial 2 For this trial you should fold your original piece of foil in half and then bend the edges up slightly (Still think cookie sheet, only it's half as big). **Q13.** Has the **mass** and/or **weight** of your foil changed as a result of this folding? ____________________________________ **Q14.** What **has** changed as a result of this folding? ____________________________________	3. In cell E3, enter the following formula: =B3 + C3 + D3 This formula will add the numbers in each of the cells to calculate Amei's total score. What is Amei's total score? ________________

In addition to the structure of the worksheet, there were other aspects that Heather considered about *Lesson Design*. Specifically, she expressed ideas about the amount of written instructions that a worksheet should have. In reflecting on her own learning using the *40 Falling Objects* worksheet, Heather thought about how the amount of reading required in the activity might impact students. "The old school lab was a little more dry. I think that it would be hard for students to sift through all the verbiage and stay focused" (Heather, Motion, 9/27/07). In contrast, Heather felt that the *41 Falling Foil* worksheet was easier to use since it had more pictures describing the process.

In Ms. Thomas' class, a large number of the students had difficulty reading written instructions and a large number of students were English Language Learners. To meet the needs of the English Language Learners, Ms. Thomas had the assistance of a full-time aide who was bilingual, speaking both Spanish and English. During the Technology Partnership Project, Heather's group had the opportunity to think about *Lesson Design* and how it might impact students who struggled to read written instructions. As her group reflected on the success of the worksheet they had designed, the reading level of the activity was discussed.

> Linda: Well actually, I think a lot of kids...that there were too many words and stuff. You know...
>
> Ms. Thomas: Yeah.
>
> Jesse: Well, I know for a couple of groups, I was able to just walk around and talk to them about, "Oh this word means this..."
>
> Heather: Yeah, I found that it was better for US to have it written down to refer to it.
>
> Ms. Thomas: It almost needs to be interpreted to them.
>
> Heather: Yeah (Heather, Plan, 2/4/08).

With these students, Heather found that having the instructions in writing enabled her to better explain to the students what they needed to know. Heather's ideas showed that she was thinking about the idea of *Lesson Design* across multiple contexts. She expressed a desire to balance some structure with open exploration and she critically evaluated the reading level of her activities and how it helped her to teach and the students to learn.

One final repeating idea emerged from Heather's work as she reasoned about teaching with technology. This idea, *Student Control*, was not as prevalent in the data as *Playing to Learn* and *Lesson Design*. However, *Student Control* was not seen in Amy's ideas, and it provided additional insight into the pedagogical decisions that Heather made. *Student Control* related to the idea that students should work with the technology themselves, and not passively watch as the teacher demonstrated how to use the technology. *Student Control* was common in Heather's teaching and she spoke openly of it in planning sessions.

In her teaching during the Technology Partnership Project, Heather decided to provide a brief introduction for formatting cells. Heather asked that the students watch her as she completed the tasks, telling the class that it was not necessary for them to follow along on their own computers (Heather, Teach, 2/6/08). Her decision to control the technology as students watched was based on an idea that students would probably not follow along as she talked, so asking them to do it was unimportant (Heather, Plan, 2/5/08). In this case, Heather did not plan to use *Student Control* and instead she controlled the technology as the students watched. However, during the execution of this plan, Heather quickly changed her tactic when she realized that the demonstration computer displayed on the interactive whiteboard had a significantly different version of Excel than what was on the students' laptop computers.

> So what you do is highlight that cell…if it will let me (Heather starts clicking on menu bar of Excel 2007 and cannot seem to find what she is searching for). Who has Excel up on their screen? Okay, mine is a little bit different than yours. What you would click on is Format. So, everyone on their computer, click on Format. File, Edit, View, Insert, and Format. Click on Format. Okay, and then click on Cells (Heather, Teach, 2/6/07).

As soon as Heather realized that her computer did not match the students' version, her instruction moved away from a demonstration of the teacher using the computer and toward an expectation that the students controlled the technology. She quickly transitioned to a *Student Control* model of teaching and used this model for the rest of her instruction.

Throughout the remainder of the unit, Heather spent much of her time working with individual students and small groups. These examples demonstrated that Heather consistently worked with students without taking control of the keyboard or mouse (Heather, Teach, 2/4/08, 2/6/08, & 2/8/08). Heather patiently stood to the side as students struggled with operating the laptop mouse, selecting the correct cells, and navigating the menu options. She worked with one student who struggled to select appropriate cells to produce a graph.

> Which ones do you highlight? Do you highlight everything? I would try to highlight this one, this one and this one, just your data. And just try to graph those data points. (Long pause as Heather looks at screen while student works the mouse). Um, click on the mouse. It is just being slow. Well, just do these numbers: 38, 6 and 9. Yeah, highlight those numbers…not that top one. (Heather laughs. Long pause as Heather looks at screen while student works the mouse). Almost, almost! (Heather

> laughs). Do you want me to see if I can help you? (Student keeps working, finally selecting the correct cells). Okay! Okay! (Heather laughs) (Heather, Teach, 2/8/08).

At times, Heather was tempted to take control away from the student during the instruction, but she resisted this temptation and instead allowed the student to remain in control. During a planning meeting, Heather reflected on her struggle with *Student Control*. "What is really hard for me is not just like--really having to tell myself, 'Don't touch their mouse! Don't touch their mouse! Hands to yourself!'" (Heather, Plan, 2/4/08).

It is unclear where Heather developed her ideas that teachers should allow for *Student Control* when teaching with technology. She abandoned this pedagogical choice at one point during the unit when she attempted to do a large group demonstration at the front of the room. However, she quickly changed this tactic when the technology did not operate as she had planned. In the remaining examples of her teaching, Heather seemed firmly committed to the idea of *Student Control*.

As Heather reasoned about teaching with technology three repeating ideas developed: *Playing to Learn*, *Lesson Design*, and *Student Control*. These ideas provided insight into the pedagogical choices that she made during the Technology Partnership Project. She saw value in open exploration of technology, but felt there needed to be some structure in place to support this exploration. She also had clear ideas on how worksheets and *Lesson Design* provided this structure while students actively used the technology to learn mathematics.

Theme II: Overarching Conception of Teaching Mathematics with Technology

The ideas that Heather expressed during the various research contexts also provided insight into her general sense of what it meant to teach mathematics with technology. Data analysis revealed two repeating ideas. The first, *Technology as an Enhancer*, was an alternate conception from Amy's idea of *Technology as an Extension*. Like Amy, Heather looked for a balance between doing mathematics by hand and doing it with technology, but Heather's stance was more tentative.

She was able to identify and enact ways that students could learn the mathematics from the technology and she saw examples where technology could be a legitimate replacement for hand calculations, enhancing student learning.

During the Technology Partnership Project, Heather's group did not use class time to teach graphing and computation by hand. Instead, all of the fraction, decimal, and percentage calculations were done using formulas and formatting features in Excel. In one lesson, Heather demonstrated the process for calculating these numbers using Excel. She began by displaying a data table on the interactive whiteboard. Figure 4.1 shows how this table appeared on the screen.

	A	B	C	D	E
1	What kind of crackers do people like?				
2					
3			Fraction:	Decimal:	Percent:
4	Ritz	4			
5	Gold Fish	1			
6	Wheat Thins	3			
7	Cheez Its	2			
8					
9	Total				
10					

Figure 4.1: Heather's Example Data Table

Students copied the data table on their own computers and then entered a formula in cell B9 to calculate the total number of people surveyed, =SUM(B4:B7). For each fraction, decimal, and percent calculation, the students used the same formula. For example, in cells C4, D4, and E4, students typed the same formula: =B4/B9. Heather then explained that to make each cell "look right" they only needed to change the cell's format (Heather, Teach, 2/6/08).

When Heather reflected on the students' learning during this activity, she felt their learning would have been much different if technology had not been used.

> And I think that you know, they would have had to do all the calculations by hand and I think that now they can go back and learn those calculations by hand, because they have some sort of context to pull from (Heather, Interview, 2/21/08).

In her instruction, Heather had asked the students to create and use formulas to analyze the data collected in their surveys. She felt that by starting with the technology, students had a context from which to draw. This context helped the students to learn the hand computation later because they knew that calculating fractions, decimals, and percents involved the same set up, just different formats.

In the interview, the researcher asked Heather to imagine mathematical concepts that would be learned less effectively if technology were used. Heather struggled for an example. Finally, she settled on the concept of factoring, and how the use of computer algebra systems might inhibit student understanding.

> I guess I'm a little bit wary of the computer algebra systems. Like with the factoring. I think it is a good tool, like once they have learned the concept. But that's touchy too, because in the real world, they would have access to that. But, I don't know. I just think they are a little, I think kids could become way to dependent on the computer algebra systems without knowing the concepts and I think that is kind of a scary area (Heather, Interview, 2/21/08).

Even in her criticism of this technology, Heather was tentative. She acknowledged that in the "real world" students had access to these tools, and that prohibiting their use might be an artificial restriction.

When asked to identify a mathematical concept that students would learn more effectively if technology were used, Heather could not settle on a particular example. Instead, she displayed a more general view of *Technology as an Enhancer*.

> Well I think you have to be careful to use it in a way that will teach beyond what you can do easily with pen and pencil, I guess. So, that's been like a real struggle for me, cause I am working on writing some learning activities using a calculator. And it is really hard to think of things you couldn't do without the technology (Heather, Interview, 2/21/08).

While she acknowledged some gaps in her own knowledge, her ideas indicated a view that technology was a way to enhance and improve instruction, allowing students to do things that were not done easily by hand. Heather did not feel that technology was a reward for students who mastered paper and pencil computations. Instead, she talked of using technology to "teach beyond" the mathematics that can be done by hand.

A second repeating idea emerged as Heather participated in the various research contexts, giving additional insight into her general sense of teaching mathematics with technology. The repeating idea, *Using the Technology*, was traced from Heather's planning for the Technology Partnership Project, to her teaching during the project, and into her reflection of the students' learning. Heather's ideas about *Using the Technology* answered the question, were students doing technology in the mathematics class or were they doing mathematics with technology? In contrast to Amy's idea of *Doing the Technology*, Heather's ideas suggested that she intended for students to do the mathematics *Using the Technology*.

During the Technology Partnership Project, Heather's group met after each lesson to reflect on that day's instruction and plan for the following day. In her interview, Heather described the group's planning process. "And [we] just went from there and just a day-by-day thing depending on the students' progress" (Heather, Interview, 2/21/08). During these planning meetings, conversations focused on how individual students progressed, and changes that could be made to accommodate these students' needs. Student needs were the driving force behind the instructional choices that the team made. The overall feel of the meetings was that the team was planning a mathematics project, and that the technology was of secondary concern.

In the lesson plans for the Technology Partnership Project, the group wrote objectives that described the students as the active agents doing the mathematics. Excel was presented as a tool for students to use as they did the mathematics. In the first lesson plan, Heather's group provided a description of the project.

> Explain the details of the project:
> a. Determine a question.
> b. Design a survey.
> c. Decide how to distribute the survey.
> d. Organize and analyze the results (using Excel).
> e. Display the results (ex. posterboard, PowerPoint, short movie,

etc.).
f. Present the results at Family Night (Heather, Lesson, 1/16/08).

Of importance was the wording of part d. Heather's team could have said, "Excel will analyze the results." However, the students were told that they would be analyzing the results, and that Excel was to be used as a tool for this process. Another example was seen in the lesson plan for January 30. One goal for the lesson was that "Students will learn that Excel can be used for graphing" (Heather, Lesson, 1/30/08). Again, the technology was being used as a tool so the student could do the graphing.

During the Technology Partnership Project, Heather led large group instruction and worked with individual student groups as well. In both contexts, she used consistent language indicating the theme of *Using the Technology* (Heather, Teach, 2/6/08, 2/7/08 & 2/8/08). Heather's choice of language during the whole group instruction of formatting cells was representative of this theme. "But, now I want to analyze my data and I want to look at it as a fraction, a decimal and a percent. And there is a certain way that you can do that using Excel" (Heather, Teach, 2/6/08). In this case she described herself as the one analyzing the data and looking at its different forms. The technology was not analyzing the data. Instead, Heather was analyzing the data, *Using the Technology* to do the mathematics.

Some of Heather's ideas, however, demonstrated that her theme of *Using the Technology* was somewhat tentative. As she reflected on the students' learning during the Technology Partnership Project, she shared that,

> So I think that in the end, like our biggest...like, I think our biggest accomplishment was teaching the kids a new technology and how to use it in a math classroom. They got exposure to different types of graphs, and they got exposure to a lot of math concepts (Heather, Interview, 2/21/08).

She was able to identify some mathematical concepts that the students learned, but Heather identified the students learning to *Do the Technology* as one of the group's primary accomplishments. So while her planning and instruction indicated a ideas about *Using the Technology*, her reflection of student learning was slightly different. Possibly, her ideas on this issue were still in flux.

Overall, Heather's ideas provided a picture of her general sense of teaching mathematics with technology. She saw technology as a tool for enhancing mathematics instruction. She shared ideas that technology could be used as a tool for learning mathematics and technology did not have to be reserved for use once students mastered hand computation. She also demonstrated the idea of *Using the Technology* to do mathematics. She planned and executed lessons that used technology as she and the students did the mathematics. However, as she reflected on students' learning, she gave slight hints of the idea of *Doing the Technology*. While theme was not widespread, its presence indicated that Heather might still have been negotiating these ideas.

Theme III: Knowledge of Students' Learning Mathematics with Technology

Heather's ideas also gave insight into how she viewed the way students learned when they used technology. The first repeating idea that was identified, *Visualizing with Technology*, addressed how the technology enabled students to visualize mathematical concepts as they learned. She spoke of this theme in the Technology and Pedagogy course when she reflected on her own learning. Later, Heather shared that she saw *Visualizing with Technology* as one of the best examples of how technology could facilitate student learning.

In the Technology and Pedagogy course, Mr. Compton had the pre-service teachers work in small groups to develop a variety of graphs using motion sensors and LoggerPro graphing software. This technology generated graphs of distance against time and velocity against time. Mr. Compton asked each group to identify one graph that they found "interesting" and share it with the class. During this sharing, the pre-service teachers displayed their chosen graph and described the movements that they used to create the graph. One group shared a graph that appeared sinusoidal. The graph of distance against time appeared to be a transformation of a cosine function, while the graph of velocity against time appeared to be a transformation of a sine function. One of the pre-service teachers shared that this method might be a way to introduce derivatives or integrals of trigonometry functions (Jin, TechPed, 9/27/07). On the class discussion board, Heather reflected on this demonstration.

> I really think that the discussion at the end was wonderful because I think that making graphs (linear and sinusoidal, perhaps) and then asking to the students to find movements that replicate them would be a great use of the motion detectors in a math classroom. And then if the idea of an integral could be added in that would be great as well (Heather, DB, 9/27/07).

Heather saw that the technology facilitated a visual representation that would help students to understand complex mathematical concepts.

Later, Mr. Compton asked the pre-service teachers to create "Rules for Graphing" that they could use when they taught graphing to their own students. Heather wrote six rules:

> 1. Give your graph a descriptive title
> 2. Label your independent axis
> 3. Label your dependent axis
> 4. Scale your graph so that it fills the given space
> 5. Use evenly spaced intervals
> 6. If not using a computer to graph, draw lines using a ruler or straight-edge (Heather, Assign, 10/21/07).

Heather's phrasing of rule six was important. She wrote as if she was assuming that the computer would be used for graphing in her classroom. Clearly, she saw that technology would play a role in the way she planned to teach graphical representations.

In the individual interview, the researcher asked Heather if she could think of a mathematical concept that students would learn better if it were taught using technology.

> I don't know of a really specific example, but I think as far as learning about the different types of graphs and different...like I am trying to think of...I can't think of the word. You know like a parabola, if you, you know, you change the number in front, you know, like it goes (laughs), different families of graphs, you could learn about them better, I think--Cause it's more real time and you know you don't have to you know, plot all the points, and do all the calculations. It is more instantaneous feedback (Heather, Interview, 2/21/08).

The National Council of Teachers of Mathematics (NCTM) Standards call for students to have opportunities to explore and create multiple representations of mathematical concepts (NCTM, 2000). For example, students should be able to connect a quadratic equation like $y = 3(x-2)^2 + 1$ to its graphical representation (a parabola). Students should also know how this graphical representation is impacted when the constants in the equation are changed. *Visualizing with Technology* was one way that Heather saw for students to explore this idea. In her answer, Heather described a lesson where students could use technology to change parameters and quickly assess how the graph changed.

Alongside *Visualizing with Technology*, a second repeating idea was present as Heather thought about students' learning with technology. During the Technology Partnership Project planning and teaching, Heather demonstrated how mathematics can move from concrete to abstract ideas when students learn with technology. This idea, *Abstraction with Technology*, was first seen when Heather advocated for a particular teaching strategy during a planning meeting with her team. After teaching this lesson, Heather reflected on the students' ability to understand *Abstraction with Technology*.

Prior to entering the licensure program, Heather shared that she had taken one formal technology class that addressed using and teaching with spreadsheets. In this class, the instructor had emphasized creating and using "dynamic spreadsheets" to help students explore mathematical concepts. Dynamic spreadsheets use formulas in calculations so that users can change parameters and the spreadsheet automatically updates. Figure 4.2 shows an example of a dynamic spreadsheet.

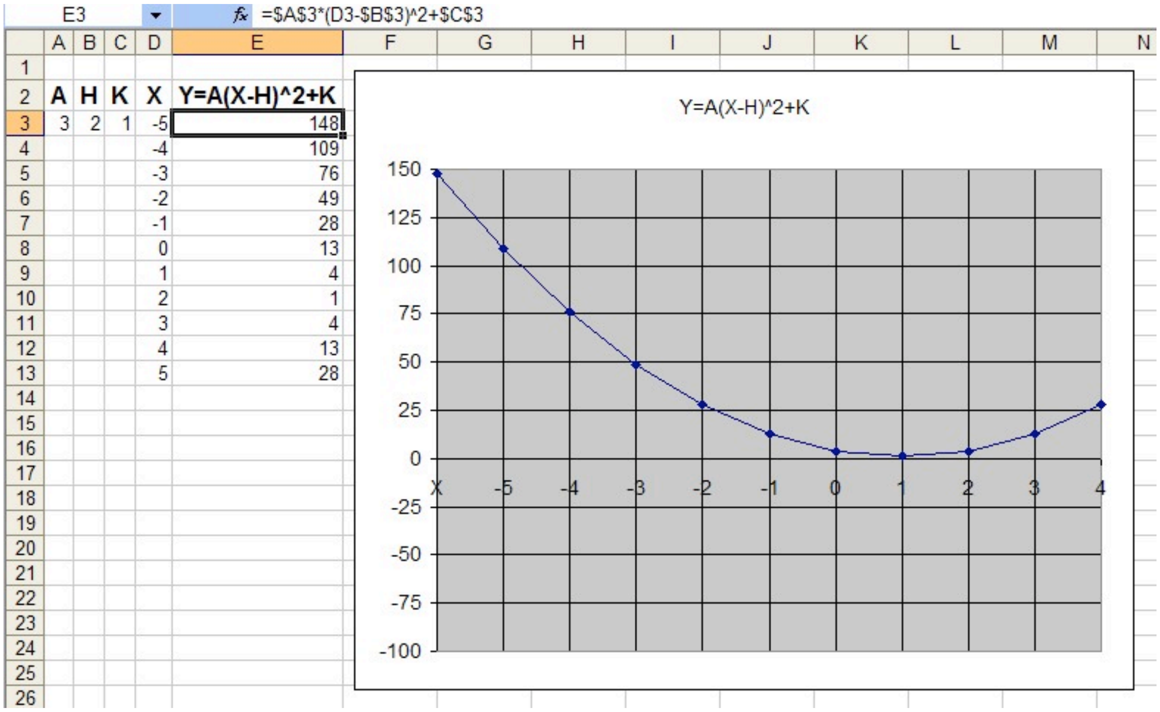

Figure 4.2: A Dynamic Spreadsheet

In cell E3, the user has entered a formula (=$A$3*(D3-$B$3)^2+$C$3). This formula used the parameters in cells A3, B3, C3 and D3 to generate the numbers in column E. The numbers in column E are plotted on the chart. A student could use this spreadsheet to investigate how the graph changed when the value of the leading coefficient was changed by simply entering a new number into cell A3. This formula is "dynamic" because changing one parameter meant that all the values in column E and the graph were instantly updated. Dynamic spreadsheets like this are useful tools for supporting students in making conjectures and testing their ideas. However, dynamic spreadsheets use variables and formulas and require students to think about mathematics in an abstract way.

In a planning meeting during the Technology Partnership Project, Heather advocated for using dynamic spreadsheets in the lesson. She suggested that dynamic spreadsheets would be useful for the students as they analyzed their survey data.

> So then, the other thing I was thinking is that it might be above a lot of the students' heads, but I want to throw it out there. Is like creating it so it is like, dynamic. So that they are putting in

> equations that involve the cell numbers in here. And not just the numbers, you know? Instead, of, like say this is cell A3, instead of putting in .75, they can put "=A3" and then they can format it so that it is decimal instead of a fraction (Heather, Plan, 2/5/08).

In a previous lesson, Heather's group had introduced formulas for adding data in a column. In spite of this instruction on formulas, many students added their data by hand and entered a static value for the "Total." Heather's group discussed the idea of dynamic spreadsheets and seemed to agree that it would be useful to try using this type of spreadsheet when the students learned to calculate fractions, decimals, and percents.

> Jesse: I think that would be good. And on their worksheet they had last time, they had that. They had "equals, this cell plus this cell plus this cell."
>
> Ms. Thomas: I don't know how many of them actually figured that out, though. I saw what you were aiming at. A lot of them just figured the numbers out.
>
> Heather: Yeah, they were counting em, and just putting them in. Which is fine if they do that for this, but I think if we could get...cause I mean the point of it is okay, say Jose comes in and he asks one more person you could just put a four in there and it automatically changes everything, and you don't have to go back and change all of your inputs.
>
> Ms. Thomas: That would be good to show.
>
> Heather: That is what I want to show them. Is like, okay I am putting in cell numbers, not just the data numbers. Making it dynamic (Heather, Plan, 2/5/08).

Heather was able to justify her use of dynamic spreadsheets by showing how it would ease the data analysis process. Ms. Thomas was concerned that the students had not understood the previous attempts at *Abstraction with the Technology*, but she was willing to let Heather try it again.

On February 6, 2008, Heather had the students enter data and calculate the fraction, percent, and decimal representation for each category of the sample cracker survey. Although students resisted the idea of writing formulas for calculations they could do by hand, Heather stayed with this choice (Heather, Teach, 2/6/08). Later, as Heather reflected on the student's learning, she felt that by forcing them to move towards *Abstraction with Technology*, she had facilitated better student understanding.

> I think it helped...one of the things it helped them understand was the similarity between fractions, decimals and percents. I noticed a lot of light bulbs going off in the kids' heads when they just had to reformat the cells. And I don't think you can see that so much pen and paper. You know the way you set them up is different (Heather, Interview, 2/21/08).

Calculating fractions, decimals, and percentages typically relies on fluency with certain computational algorithms. In this case, Heather used spreadsheets to calculate these values in a way that highlighted the similarities among fraction, decimal, and percentage computations, while masking the differences in the algorithms. She saw this *Abstraction with Technology* as facilitating student understanding with technology that was not possible with traditional methods.

A third and final repeating idea developed as Heather thought about students' learning with technology. Like Amy, Heather showed ideas consistent with the theme of *Motivation*, the excitement and fun of using technology to learn. During the Technology and Pedagogy course, Heather spoke of factors that motivated her own learning. In her teaching, Heather did not use language consistent with theses ideas, and she reflected later on whether the technology she used in the Technology Partnership Project influenced the students' level of engagement.

During the Technology and Pedagogy course, Heather's instructor had the pre-service teachers do an investigation called *Who's Prettier: David or Victoria?* This activity explored the Golden Ratio using photos imported into Geometer's Sketchpad. The pre-service teachers used Geometer's Sketchpad to make measurements of two faces (David Beckham's and Victoria Beckham's) and calculate various ratios like (width of the eye) : (width of the iris). The pre-service teachers used these measurements to substantiate claims about which of the two faces more closely fit the Golden Ratio, i.e. which face was more beautiful. On the class discussion board, Heather reflected on the activity.

> I really enjoyed the assignment of looking at the Beckham's (sic) faces. This is something that I would love to do with my future students within the first week of school to introduce them to the software, and to let them have some fun as well! (Heather, DB, 10/26/07).

Heather thought that the connection to pop culture and the use of digital images made the activity enjoyable as a learner. She could also foresee this activity as something that students would enjoy and find to be fun.

As Heather taught, she actively tried to make connections with students. She was the first in her group to learn the names of all of the children in the class and she was often able to share individual stories about the children during the group planning meeting (Heather, Plan, 1/29/08, 2/4/08, 2/5/08, & 2/8/08). When one student showed a special interest in the color pink, Heather made a point of bringing in special pink paper for that student to use (Heather, Teach, 2/8/08). Clearly, Heather made a special effort to connect with the students in the classroom. However, in her teaching, Heather did not express a particular excitement regarding the technology. With the exception of the graphing worksheet *Mini Golf Graphing Challenge!* Heather did not express any ideas about technology in her teaching that showed the theme of *Motivation* (Heather, Lesson, 1/30/08).

In addition to the final project, Heather's group gave the students a survey as a final assessment at the end of the project. This assessment measured some of the affective goals of the project. Some sample questions were:

> How did you feel about this project when it was first introduced (eg. nervous, disappointed, excited, etc.)? Please explain in 1 or 2 sentences.
> How do you feel about this project now that it is finished? Please explain in 1 or 2 sentences.
> If we did this project over again, what would you change? (Heather, Lesson, 2/14/08).

Heather shared that she was surprised by the way that students responded to these questions.

> And, there were a lot of students that seemed really disengaged and uninterested that actually really enjoyed it. And some of the kids that we thought were really into it really hated it! (laughs) And so, I am kind of focused on the kids that I thought weren't really interested, and just I am really amazed at how much they got out of it that I totally didn't even see coming (Heather, Interview, 2/21/08).

In her teaching, Heather thought she knew what motivated the different students, but the final assessment conflicted with her ideas.

In spite of this, Heather still felt that *Motivation* was an important idea regarding students' learning with technology. When the researcher asked how the students' learning was impacted by the use of the technology, Heather's ideas focused on *Motivation*.

> But, I think also maybe just the, I don't know what the word is, but just kind of the excitement of using the computer and being able to use technology get kids more involved. Whereas if we would have done the same thing up on the SmartBoard or something they may have just tuned out (Heather, Interview, 2/21/08).

This idea also was connected to Heather's prior ideas about *Student Control*. In this example, she described how students were more motivated by the control of the technology and not just the presence of technology in the lesson. Later, she reflected on how the students' learning would have been different if technology had not been used. Again, the idea of *Motivation* was expressed as Heather spoke about the students' level of engagement.

> I think the kids would have been really frustrated. Because, I think we would have been teaching it more algorithm based...But, yeah, I think they would have just got really frustrated and disengaged if we hadn't used the laptops (Heather, Interview, 2/21/08).

Heather's ideas showed that she saw *Motivation* as important when thinking about students' learning with technology. She expressed *Motivation* in her own learning and talked about how it could influence students' learning. Her teaching lacked examples of *Motivation* in practice. However, as she reflected on her practice, it was clear that Heather thought technology was an important tool for maintaining student engagement.

Jesse

Introduction

Jesse had always enjoyed studying mathematics. In his interview, he compared mathematics to other subjects, like English, where he said you could work and work and never find an answer. In contrast, Jesse shared that he liked mathematics because there was always a "correct answer" that he could find (Jesse, Interview, 2/21/08). He also talked of a sense of accomplishment that he felt when he solved mathematics problems.

> You know, whereas a math problem, you can work on this problem, work on the problem, Oh! I found this nice elegant way of showing what I got, this is the answer, yep, it's right. Done. You know? And you can feel that thing (Jesse, Interview, 2/21/08).

Jesse shared that he got this same feeling of accomplishment when he worked with computers as well.

> And it is kind of the same thing with computer science is that you kind of work on it and it is really frustrating, but then you kind of have this moment where you figure it out. And then it works really well and you have this nice finished product (Jesse, Interview, 2/21/08).

In the interview, Jesse talked of affection for technology as well as mathematics. As a child, Jesse's home was filled with technology. In team planning, Jesse described himself as being "the one with the dad who really liked technology" and how his family was on the cutting edge of Internet access at home (Jesse, Planning, 2/8/08). In the interview, Jesse described the technology he had at home.

> And then it was kind of neat, and then I also like, even my dad was always into computers and we always had a computer growing up. And, we were one of the first houses in our area, you know, that had Internet, you know, one of the really old dial up Internet (Jesse, Interview, 2/21/08)

At school, Jesse also had access to formal instruction with technology. He described two technology teachers with whom he felt a strong connection. One teacher taught a class where Jesse learned to program computers using the HyperText Markup Language (HTML). The other teacher was a former art teacher who taught Jesse to use Adobe Photoshop and Adobe Premiere. Experiences both in and outside of school gave Jesse confidence in his ability to use technology and to teach himself to use new technology tools. In a planning meeting, Marsha Thomas asked the group about their technology skills.

Ms. Thomas: So you guys are like really computer savvy? (laughs)

Heather: I usually consider myself pretty savvy, yeah.

Jesse: We're savvy. (laughs) I like computers. I mean, yeah. I can do most things that I want to do. Most of my computer stuff is stuff that I just played around with and figured out. Especially with computers, I do a lot of...I like a lot of digital photography and that type of stuff. And doing Photoshop kind of things also.

Ms. Thomas: Okay. Oh neat!

Jesse: And doing all kinds of different stuff. I like to play around with computers (Jesse, Plan, 1/14/08).

Jesse shared a strong history of using technology in his personal life and in school. However, he did not share any experiences using technology to learn mathematics. In the Technology and Pedagogy course, Jesse reflected that while he had used many of the software tools, some were new to him. “Although I was a math and computer science double major it is kind of strange to learn that I had never used Sketchpad before. I have wanted to use it for a while (sic) now but have not had the opportunity to use it until last class” (Jesse, Assign, 10/24/07). He also indicated that his experience with technology for teaching was limited as well. He shared a lack of experience, but a strong interest, in using interactive whiteboards and classroom remote response systems (e.g. Classroom Performance

Systems (CPS)). In one Technology and Pedagogy class, Jesse spoke with a group of pre-service teachers about this interest.

Hillary:	We have a SmartBoard, so that is good!
Heather:	That is COOL!
Jesse:	I have still never used one. But I really want to.
Amber:	Really?
Heather:	I haven't either.
Amber:	I have seen it used, but…
Jesse:	I have seen (names his cooperating teacher) use the CPS thing. And I have always wanted to use it actually.
Heather:	I have used the CPS things.
Jesse:	I just haven't had a chance yet (Jesse, TechPed, 9/27/07).

In the Technology Partnership Project, Jesse taught with Heather and Linda in Ms. Thomas' class. An overview of the unit and individual lessons was described in Heather's narrative and not repeated here. One additional aspect unique to Jesse's experience in the Technology Partnership Project was noteworthy, however. In the initial team planning meeting, Jesse advocated for designing a unit that allowed students flexibility to choose the form of their final product. He suggested that in addition to a poster, students might choose to make a PowerPoint presentation or a video (Jesse, Plan, 1/14/08). He offered his experience with editing digital video as a resource for the students, and he took on the responsibility of working with the two groups who chose to do a video.

Jesse's ideas were an important contribution to the results of this study. He reported a strong confidence as a mathematician, but he also had a rich history using technology. His score on the General Preparation Profile Survey was the second highest of the group (65), indicating his confidence with using technology tools. His background using technology to learn and teach mathematics was limited prior to starting the licensure program. The strength of his prior knowledge, however, made an examination of his ideas important. For this reason, a detailed description of the themes that emerged from his ideas is provided.

Theme I: Pedagogical Reasoning about Teaching Mathematics with Technology

As Jesse participated across the various contexts of the study, repeating ideas were found in his work. When he reasoned about teaching with technology, three repeating ideas were shared by Jesse. As with Amy and Heather, *Playing to Learn* was also expressed in Jesse's ideas. As a learner, Jesse found *Playing to Learn* to be a useful strategy. He was able to identify drawbacks to *Playing to Learn*, but he felt that the benefits were more important. In the planning meetings, Jesse advocated for *Playing to Learn* as a pedagogical strategy that helped the students, and he used this strategy in his own teaching during the Technology Partnership Project.

When Jesse talked about his own learning, he described how *Playing to Learn* worked for him.

> With a lot of the technology, I am more like self-taught on it. You know, like I just went home and I am like, "I need to do this." So I figured out a way to do it. And it is probably not the textbook way, the most efficient way, but for me, I know how to do it (Jesse, Interview, 2/21/08).

Jesse recognized that *Playing to Learn* might not be the most efficient way to learn, but he shared that it worked for him. In the Technology and Pedagogy course, Jesse reflected that the motion senor lab was fun for him because it allowed for open exploration of the technology. "I enjoyed the inquiry part where we had the chance to 'play' with the cool toy and try to be detectives and figure out how it works" (Jesse, DB, 9/28/07).

Jesse found *Playing to Learn* a useful and fun way to learn on his own. In the Technology Partnership Project, he had an opportunity to try this strategy with students in a mathematics classroom. During one planning meeting, Jesse's group talked about the best way to teach the students to graph using Excel. In this exchange, Jesse advocated for *Playing to Learn* as a way to teach the children to graph.

> Jesse: Do you think for the graphing example, I was thinking I could have the data from that Excel thing (worksheet) and I could make the graphs. I could make a bar graph out of it, a pie and whatever.
>
> Linda: I think that's what you should do.
>
> Jesse: And then part of it could be like, "Okay, well and if you get done with that, can you try to make these that I made?" You know, kind of thing. Like , don't go through explaining how to do it, but just say, "See this up here? Try to make that. How would you make that?" Have them play around with it.
>
> Linda: That would be good.
>
> Jesse: Have them try to get those results that I have up there. And that can, uh...
>
> Linda: And make it, um, I want them to want to do that. Make them excited like, "I want to finish this, because I want to try that because it looks like fun."
>
> Jesse: Yeah, yeah. Like, "Can you make this?" You know, kind of thing. Make it a challenge.
>
> Linda: Yeah, that would be really good (Jesse, Plan, 1/29/08).

In this discussion, Jesse defended the pedagogical choice of *Playing to Learn* and Linda agreed. He justified this strategy by contending that if students *Play to Learn*, they would be more engaged. He saw this strategy as a more useful technique than just "explaining how to do it." Jesse's ideas were taken up by the group, and the majority of Lesson Five was spent with students working on *Mr. Slade's Graphing Challenge* (Jesse, Lesson, 1/30/08).

In Lesson Five, Jesse took the lead when graphing was introduced. He started this part of the lesson at the front of the room with Excel displayed on the interactive whiteboard. Jesse had taken the data from the previous day's worksheet, *Practice with Excel*, and created three graphs from the data. Figure 4.3 shows the image that Jesse displayed.

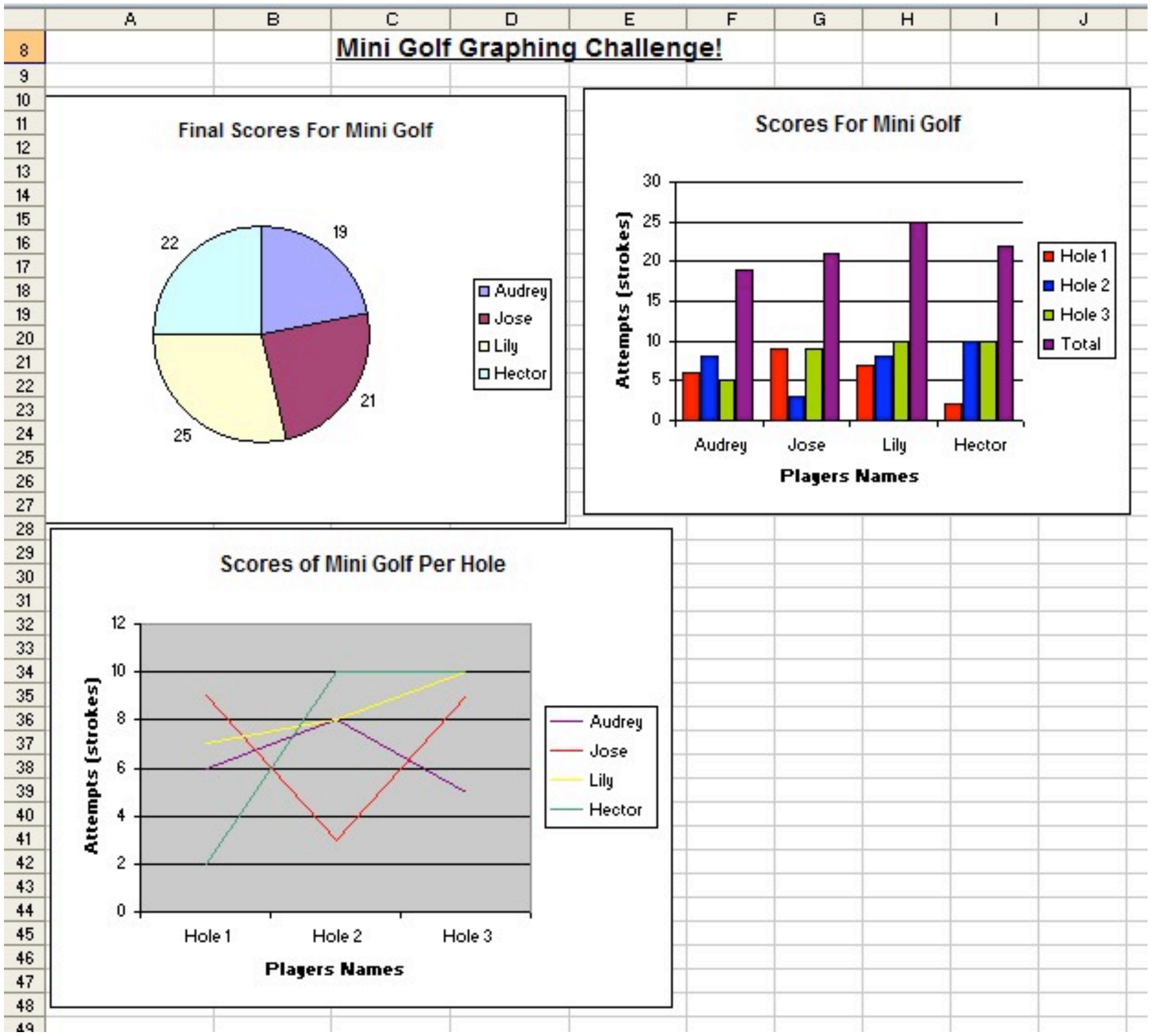

Figure 4.3: Mr. Slade's Graphing Challenge

Some of the students had not completed the *Practice with Excel* worksheet, and Jesse presented the three graphs as a challenge for the students once they were done. He did not explain how he had made the graphs, he just showed the final product. Rather than demonstrating the process, Jesse challenged the student to figure it out on their own.

> So this is all the data that you had typed in. And from this, I created three graphs. So my challenge to you, after you finish this worksheet, is to try to recreate these three graphs. And if you finish these three, you can try other ones also. You can try other

> graphs if you want to. Okay. Does everyone understand what we are doing? Okay, so you can go ahead and start working on your worksheet. And if you have a question about those, you can go ahead and ask us (Jesse, Teach, 2/4/08).

Lesson Six followed *Mr. Slade's Graphing Challenge*. In this lesson, Heather used the strategy of *Playing to Learn* to teach the students to format cells in Excel. A detailed description of this lesson appeared in Heather's narrative and is not repeated here. After the lesson ended, the group reflected on the effectiveness of teaching students to format cells in this way. As he talked with Heather, Jesse imagined how open-ended exploration might help students to remember formatting techniques in the future.

> Jesse: You have to format it and say, "I want all of this column to be…"
>
> Heather: To be fractions.
>
> Jesse: To be fractions, I want this column....I guess if you just put up like a...the place to find it. I guess, I don't know what that menu is called. I think they will be able to go, "Oh, I need to go to Cell Options, where is that? Oh, there it is!" Click on it. "Okay, percent!" A lot of it, I think after you kind of find like, the hardest part is finding which menu to go to, I think. As soon as you have that menu, doing it comes back. So how to highlight a complete column, how to change... how to go to Format, Cell (Jesse, Plan, 2/5/08).

Jesse saw *Playing to Learn* as a strategy for building a disposition about technology that could help students troubleshoot problems they encountered later on as they worked with technology. While he recognized that *Playing to Learn* was not always the quickest path, Jesse's ideas indicated that this strategy was effective for his own learning and the learning of the students in his class.

A second repeating idea developed as Jesse reasoned about teaching mathematics with technology. This idea, *Lesson Design*, was also seen in the ideas of Heather and Amy. For Jesse, this theme did not seem to be as important. He reflected on *Lesson Design* during Technology and Pedagogy. There was also evidence that he considered *Lesson Design* during his teaching. However, Jesse shared fewer ideas related to *Lesson Design* than either Amy or Heather.

After finishing the motion sensor activity in the Technology and Pedagogy course, Jesse contrasted the *Lesson Design* of the *40 Falling Objects* worksheet and the *41 Falling Foil* worksheet. He reflected that the *41 Falling Foil* activity "seemed more inquiry based and had more 'big picture' ideas" than the other lab (Jesse, Motion, 9/28/07). In thinking about the experience in general, Jesse explained that having a particular *Lesson Design* enabled him to learn the lesson objectives.

> I think having the experiments lab sheet as a handout would have helped focus our group during that part of the lesson. By doing inquiry first I was able to establish my own ideas of how it worked before being told how it worked (Jesse, Motion, 9/28/07).

As a learner, Jesse found that the *Lesson Design* provided needed structure to focus his group. Because the design of the lab started with open exploration of the tool before formal instruction, Jesse felt he was able to learn the tool for himself. This structure also motivated him to learn to use the motion sensors.

> The falling foil labs tries to get that the more practical big picture questions and when reading the falling objects lab I found myself just skipping over large portions of it because it seemed boring. Part of the fun of doing the lab is to have an exciting representation of how science or math works in real life. If it is made dry then what was the point of the experiment (Jesse, Motion, 9/28/07).

During the Technology Partnership Project, there was evidence of *Lesson Design* in Jesse's own teaching. The middle school students were given time for open exploration time with Excel followed by some structured instructions. When one of the children asked for the purpose of doing *Mr. Slade's Graphing Challenge*, Jesse answered, "This is just a practice because you are going to have to use this for your surveys. We want to make sure that everyone is comfortable using it first. Okay?" (Jesse, Teach, 1/28/08). Jesse felt that students learned best when they were allowed time to learn to use the technology on their own, rather than through whole group instruction. However, he also saw value in a *Lesson*

Design where open inquiry was followed by some structure that ensured all students had learned what they needed to know.

A third and final repeating idea emerged as Jesse reasoned about teaching with technology. While not present in Amy or Heather's work, the idea of *Equitable Access* appeared in Jesse's ideas across the various research contexts in which he participated. In the Technology and Pedagogy course, Jesse shared ideas about his perception of students as technology users. Later, this perception was impacted by his experiences in the Technology Partnership Project. Reflecting on these experiences, Jesse talked about how technology could provide underachieving students *Equitable Access* to important mathematical ideas.

In the Technology and Pedagogy course, Jesse reflected on how he might use technology like Geometer's Sketchpad in his own teaching. Jesse described his own childhood as filled with technology resources. At the same time, he acknowledged that this environment was not common for all students. He described the types of students that he felt needed to have access to technology tools.

> In this day and age most students have computers at home and feel comfortable using them. However, there are still many students that for many different reasons do not have this luxury. Computers many seem scary since so many other students understand them and they do not understand them as well. When teaching a lesson using any computer application I would like to consider the students for which using the computer is not as easy (Jesse, Assign, 10/24/07).

Jesse shared ideas that indicate his desire to provide *Equitable Access* to technology for students who do not have access outside of school. He wrote about how he might be able to meet those needs through his own teaching.

In the initial planning meeting for the Technology Partnership Project, Jesse asked Ms. Thomas about the types of students in the classroom. He was curious to know their background and experiences using technology. Ms. Thomas answered that she had not used technology with this particular class. She estimated that one-third would have experience with laptops and know how to use them. However, she shared that for many of the children, school was their only opportunity to use computers (Jesse, Plan, 1/14/08).

During the Technology Partnership Project, Jesse was able to compare his own background and experiences with those of the middle school children. During planning meetings, Jesse reflected on this comparison sharing that he now realized how fortunate he was in his school to have access to such advanced technology (Jesse, Plan, 2/4/08). At one point during instruction, Jesse pulled a student aside and asked the student to share his own ability to access technology tools. Jesse reported this conversation during a planning meeting:

> Well, I was talking during my interview with Hector…I was like, "Oh well do you like computers and that kind of thing?" And he was like, "Yeah, I do." And I said, "Good. Do you have a computer at home or do you have access to computers very much?" And he is like, "Yeah, we have one at home but it's really old and we don't have the Internet, and so I don't really use it ever. Cause it is not very fun." And I am like, "Oh, well what kind of programs do you like? What do you like to do that you don't have?" And he is like, "Oh, well I really like, you know, to play around on PowerPoint." So when he was like, "Oh, I will do the PowerPoint thing." It gave him the chance to do it on the computer. It is interesting, I don't know anything about his real background or anything or that kind of stuff. But he wants to use technology, but he doesn't have good access unless he is here (Jesse, Plan, 2/8/08).

In the initial planning meeting for the Technology Partnership Project, Jesse had advocated for students to have options for their final project: a poster, PowerPoint presentation, or movie. In reflecting on the conversation with the student, Jesse talked about his satisfaction that the student was getting to use PowerPoint, a software program that the student enjoyed using. Jesse acknowledged that the only way the student could have *Equitable Access* to this software was at school, in Jesse's class. In the final planning meeting, the group reflected on what the students had gained through their experiences. Jesse felt that merely having access to the technology was a valuable outcome for the students (Jesse, Plan, 2/ 21/08).

As Jesse reflected on the Technology Partnership Project, his pedagogical reasoning focused heavily on providing his students *Equitable Access* to technology. To Jesse, *Equitable Access* meant giving students opportunities to not only use the technology, but also to use the technology to learn more interesting mathematics.

> It's kind of similar to that where I think that it can help more advanced topics, instead of just having the students practice really basic things forever and ever and ever and get really bored and hate math. Versus, okay, you don't really understand, you kind of do this, you made a lot of errors, but let's go deeper in math where it is kind of more fun. And then after they have those ideas, "Oh, math can actually be fun!" Then they'll be more motivated to go back to learn their algebra and stuff (Jesse, Interview, 2/21/08).

Later in the interview, Jesse spoke of his experiences working with a middle school student on a logic problem. The student was motivated to solve the problem and found a solution before many of his classmates. When Jesse spoke with the classroom teacher about this particular student, the teacher shared that the student was receiving special education services, and that the teacher had been told to only work with the student on mathematics skills like single-digit multiplication. Jesse was struck by how successful the student was with mathematics that did not depend on knowledge of arithmetic facts. He described this situation as analogous to how technology could enable students to have *Equitable Access* to more interesting mathematics. "With technology, it is kind of the idea that you can use logic and explore things that you wouldn't be able to if you didn't have it. It is like it can be helpful I think" (Jesse, Interview, 2/21/08)

After the Technology Partnership Project, Jesse reflected on the role that the technology played in student learning. He commented that if the lesson had been taught without technology, it would have focused more on procedural skills like the long division algorithm or converting fractions to decimals. The interviewer asked Jesse about the role technology would play in his own teaching in the future. He replied that there were things he liked about technology and that one was "…the fact that you can do the more advanced math, and you don't have to do the grind of doing all that computation, that kind of thing" (Jesse, Interview, 2/21/08). Jesse saw that technology allowed students access to mathematics beyond procedural computations. He also shared that this access could potentially help to remove barriers that kept some students away from higher level mathematics.

> And so I think a lot of time, it seems like the more procedural, the lower level math that you really have to, it is the basics that you need to know so that you can go higher in math. But at the same time, I think it is where a lot of people get frustrated in math also (Jesse, Interview, 2/21/08).

Jesse spoke of issues of *Equitable Access* in his initial coursework during the Technology and Pedagogy course. His experiences in the Technology Partnership Project gave him further insight into what access meant for actual students and how his teaching might address some of these issues. As he reflected on the experience, Jesse's ideas went beyond just *Equitable Access* to technology. Instead, his ideas addressed how access to technology might lead to *Equitable Access* to more advanced mathematics.

Theme II: Overarching Conception of Teaching Mathematics with Technology

Jesse's general sense of teaching with technology was seen by the ideas he shared across the research contexts. From these experiences, repeating ideas emerged. In Amy and Heather's narratives, repeating ideas about technology as a way to simplify, extend, and enhance instruction were described. For Jesse technology was one way to provide differentiated instruction, instruction that met the needs of students with a variety of abilities. This repeating idea, *Technology for Differentiation*, first appeared as Jesse's team planned for the Technology Partnership Project. He carried these ideas into his teaching practice during the Technology Partnership Project instruction. As he reflected on this instruction, Jesse spoke of how technology was used as a way to provide a unique experience for each student.

In the initial planning meeting for the Technology Partnership Project, Jesse's group talked about the type of final product they would expect the students to produce. Jesse had knowledge of a variety of technology including Excel, PowerPoint, and video editing with Premiere. He suggested that students should have options for their final project.

> I think it will be nice having a project like this where they are doing the project and so the students who want to be more advanced and do the more complicated stuff give them free reign to do that more. And then kind of help out the other student with the extra help they are looking for (Jesse, Plan, 1/14/08)

He argued that by allowing students a variety of technology options, students had the option of pursuing more complicated tasks—freeing up teacher time to help students who were struggling.

Jesse's team agreed with the idea of using a variety of technology to differentiate instruction and the students were given a number of options for their final project. In the lesson plan for Lesson Three, the team described the options that students were given.

> A. Give students the opportunity to decide, in their groups, how they want to present their survey results at Family Night (eg. PowerPoint, short video, slide show—really push for creative ideas).
> B. Each group will post their idea up on the SMARTBoard for the class to see (Jesse, Lesson, 1/24/08).

Jesse's knowledge of the PowerPoint and Premiere software was essential during the instruction. All of the team members had experience with PowerPoint, but Jesse had advanced skills with the software and described himself as a "huge PowerPoint snob" (Jesse, DB, 10/25/07). Using this knowledge, he was able to help the students troubleshoot problems and enhance their presentations (Jesse, Teach, 2/7/08 & 2/8/08). The other team members did not have experience with video editing, so Jesse worked closely with the two small groups that chose to make videos. In the Technology Partnership Project, students had a variety of technology available to them, and each group had a somewhat different experience based on the technology they chose to use.

Jesse also had ideas about how students' experiences could be differentiated when they worked with only one tool. In the Technology Partnership Project, Jesse's group expected the entire class to complete some part of their project using Excel. In a planning meeting, the group discussed how to address the students who had not finished this required task. Jesse offered one solution for a student who was not working well in a small group:

> Jesse: Maybe we could give him some kind of survey results and figure out, see if he can figure out what it means. You know, like, "We notice that your group didn't really do a lot of you know, didn't collect a lot data and stuff like that. Well, here is some data from this. You know? What can you do with it? You know? Can you…"
>
> Ms. Thomas: I think that would be perfect. Have him do an Excel thing and do the graphs. Sure.
>
> Jesse: So he shows that he knows how to do it, he just didn't want to work in a group and do that.
>
> Ms. Thomas: He is not a group person. (Jesse, Plan, 2/8/08)

In this exchange, Jesse offered an alternate assignment, one where the student could be given new data to analyze on his own. The student would still meet the unit learning objectives, just in a different way than his peers.

After the Technology Partnership Project, Jesse reflected on the learning objectives from the unit. He spoke in the interview of how students had learned both mathematical and technology skills during the project. As he described these objectives, he shared the idea that technology could be used for differentiating instruction.

> The initial like learning objectives that we had were to represent numbers using fractions, percents and decimals. And also to use, kind of utilize technology in that in some way. And we were trying to keep it really open on how we wanted to do that. So if we wanted you know, if the students wanted to do video editing or on PowerPoint, or any of the different products, then we could figure out a way of letting them use those things (Jesse, Interview, 2/21/08)

Jesse's ideas showed a general sense of teaching with technology as a way to provide unique experiences to students. This differentiated instruction did not lead to all students learning all of the tools. Rather, Jesse saw *Technology for Differentiation* as a way to give students choice and control in their own learning.

As Jesse participated in the various research contexts, he repeated another idea that gave insight into his general sense of teaching with technology. In the previous narratives, Amy and Heather talked of *Doing the Technology* and *Using the Technology* to do mathematics. For Jesse, his initial ideas were firmly grounded in a view that students should be *Using the Technology* to do mathematics. However, his experiences in the Technology Partnership Project caused him to reflect on how successful his group had been at facilitating this goal. In the interview, Jesse shared that while he felt the unit had turned into students *Doing the Technology*, he still had firm commitment to the idea that students should be *Using the Technology* as a tool for learning mathematics.

In the Technology and Pedagogy course, Jesse reflected that while he had used a lot of the technology before, he appreciated learning how to teach mathematical concepts with them (Jesse, DB, 10/24/07 & 10/25/07). In his reflections, Jesse distinguished between the knowledge necessary to use technology with the knowledge necessary to teach with technology. In his writing, Jesse imagined that as a teacher, he could design lessons that used the technology to learn the mathematics.

> One of the advantages that teachers gain is that they can assign tasks that use computers and the students can learn by exploring the software. This is great for both the student and the teacher since the students can learn higher level concepts by using the technology at hand. This gives the students a better understanding of the conceptual knowledge and gives the teacher a tool for instructing to this goal. It is a win, win situation (Jesse, Assign, 10/24/07).

In this passage, Jesse described an idea that students should be *Using the Technology* to learn "higher level concepts" and teachers should be *Using the Technology* as a tool for instructing.

Although Jesse could imagine a classroom where students were *Using the Technology* to learn mathematics, actually teaching that way was more problematic for him. As previously described in Heather's narrative, the unit objectives during the Technology Partnership Project shifted from a mathematical focus to a focus on *Doing the Technology*. Jesse reflected on this shift in his interview.

> It ended--we didn't really completely stick to that completely. I don't think there was as much emphasis on different percents, decimals and that kind of thing. We also taught Excel and that ended up being the biggest technology part of it, was that all the students worked with Excel. So, I think it ended up being more of a technology unit than using math and so it became more how to put things into Excel, how to use Excel, how to graph with Excel, kind of lesson. And then, also, some other pieces, like the group that did the video (Jesse, Interview, 2/21/08).

Jesse acknowledged that some of the mathematical goals for the unit were put aside and replaced by a focus on learning the various technologies themselves.

In spite of this experience during the Technology Partnership Project, Jesse still seemed committed to the idea that students should be *Using the Technology* to do mathematics. When the researcher asked Jesse how the students' learning would have been different if they had not used technology, Jesse answered that the unit would have taken longer, and focused more on procedural calculations like long division. He gave examples of how *Using the Technology* to learn the mathematics had impacted the students.

> I think with the graphing, I think it helped them a lot. It is just the idea of being able to create the graphs very easily. And if you mess up and it doesn't look right, you can play around with it. And have a graph in a few seconds again and if that doesn't look right. Which kind of goes back to my idea of like PhotoShop and stuff where I have this problem and I need to be able to do it. So, for the graph, you try it and if it doesn't work, you try it again. And you kind of learn the process of what you did to make it work and you can even kind of learn what didn't work and why it didn't work (Jesse, Interview, 2/21/08).

Here Jesse connected his own practice of *Playing to Learn* with the ways that students could use technology to learn to graph. The technology tool enabled the students to create multiple graphs, testing and revising their process as they went. In this passage, Jesse described this technique of testing and revising as a way to learn about graphing while using the software.

Jesse shared repeating ideas that demonstrated his general sense of teaching with technology. One of these ideas, *Using the Technology*, was challenged by Jesse's experience in the Technology Partnership Project. However, as he reflected on the experience, he could still imagine concepts that could be learned if students were *Using the Technology* to learn mathematics. Taken together, the ideas of *Technology for Differentiation* and *Using the Technology* provided insight into Jesse's general sense of teaching mathematics with technology.

Theme III: Knowledge of Students' Learning Mathematics with Technology

Jesse also shared ideas that related to students' learning with technology. These ideas appeared during Jesse's coursework, his planning, his teaching, and in his reflection of the Technology Partnership Project. The first repeating idea that Jesse shared addressed how students *Visualize with Technology*. Jesse initially shared firm convictions that students should master mathematical concepts by hand before moving to computer-generated representations. However, as he progressed through the Technology and Pedagogy course, his stance became more tentative. In the end, as he reflected on the Technology Partnership Project, he was able to identify multiple mathematical concepts that would be better learned if students could use technology for visualizing.

In the middle of the Technology and Pedagogy course, Mr. Compton gave the pre-service teachers a graphing assignment. The pre-service teachers had the option of completing the assignment using Excel or with a hand drawn graph. Jesse chose to create four graphs using Excel and his graphs had added features like data tables and curves of best fit (Jesse, Assign, 10/16/07). Mr. Compton had not taught graphing with Excel in the Technology and Pedagogy course, so Jesse's work indicated strong prior knowledge of the software. When asked to reflect on the graphing assignment, Jesse shared that it was important for students to learn to graph with technology like Excel. However, he thought that students would understand *Visualizing with Technology* more if they had mastered graphing by hand first.

> When teaching graphing to students it is important [to] know both how to graph by hand and how to graph using software such as Microsoft Excel. Both have many benefits but I believe it is good to know how to graph by hand so that it is easier to transfer that understanding to software that allows graphing. Then when graphing using software it can be more meaningful and the student can expand their understanding of graphing (Jesse, Assign, 10/16/07).

In a small group and large group discussion of this issue, Jesse's stance became more tentative. At one point in the class, Mr. Compton asked the large group whether any of them thought that you could teach graphing by starting with computer-generated graphs. Jesse did not say yes, but after a moment, he raised his hand to speak.

> Jesse: Now I can see where you can start with it by hand. I see it a lot like using calculators in classes. Where like you can start…you have to know the basic things…how to add, how to multiply. But after you want to go to more advanced topics, it is kind of a tedious thing to have to go and add and divide things by hand all the time. So, using a calculator can let you, uh, kind of expand what you are teaching to more advanced topics. And you can do things quicker and you cover more of those, instead of just staying with the really basic stuff. Where, you know, having to do huge graphs by hand just seems like doing a tedious task.
>
> Mr. Compton: So instead of taking all period you can make a good graph that you can use the next day to interpret the results of your experiment. You can do it in 10 minutes on your computer.
>
> Jesse: And spend more time.
>
> Mr. Compton: And interpret your results of that experiment. Is that what you are saying?
>
> Jesse: Yeah.
>
> Mr. Compton: Okay. But you are also suggesting starting out with learning all the steps by hand.
>
> Jesse: Yeah.

Mr. Compton: Then switching. Okay (Jesse, TechPed, 10/14/07).

In this exchange Jesse began to share an idea that addressed the benefits of students using technology to visualize more advanced mathematical ideas. However, in the end, when pressed by Mr. Compton, Jesse admitted that students should start out with hand graphing first. His ideas about *Visualizing with Technology* appeared tentative at this point.

As the course progressed, Jesse was able to experience learning with different technology in Technology and Pedagogy. Two of these, Geometer's Sketchpad and ImageJ, were unfamiliar to Jesse prior to starting the licensure program. As he reflected on his own learning with this technology, Jesse imagined ways that the software could be used to help students visualize mathematical concepts more clearly. He felt students might find ImageJ useful as they "explored" ratios, scale, measurement, and histograms (Jesse, Assign, 10/24/07). He also reflected on how his own past teaching experiences might have been more effective if he had used Geometer's Sketchpad to help students visualize properties of inscribed and circumscribed circles of a triangle.

> At the beginning of the school year I taught how to construct inscribed and circumscribed circles of a triangle. This would have been much easier and more productive with the use of Sketchpad. I told the students that the way we constructed these circles would work for any triangle, however with Sketchpad they could have dragged the triangle around and seen first hand how the circles worked. This concept would have been more alive if they could have explored this subject further using Sketchpad (Jesse, Assign, 10/24/07).

In the Technology Partnership Project, Jesse's group taught a unit that started with students designing a survey and collecting data using the survey. After the data were collected, Jesse's group discussed the next step in the unit: graphing. Hand graphing was never discussed, and the emphasis in the meeting was on how Excel could be used to generate graphs. Ms. Thomas was unfamiliar with the graphing capability of Excel, and the group described it to her. Jesse shared that by using Excel for graphing, the students could make multiple representations of the data and then focus on which representation helped them to visualize it best. “We were thinking about having each of the students do a different kind of graph and then looking at the differences and which one represents their data the best. So like do the pie chart for this or the bar graph” (Jesse, Plan, 1/29/08). Jesse advocated for *Visualizing with Technology* as a way to help students understand the data that they collected.

After the Technology Partnership Project, the researcher asked Jesse if he could think of a mathematical concept that students would learn better if it were taught using technology. He offered two concepts and both involved *Visualizing with Technology*. Like Heather, Jesse saw that technology could help students connect algebraic representations with graphical representations.

> The graphing I think is one I talked about a little bit. The fact that you kind of experiment with the graph, you know. Um, like using...being able to change where the line is and see what it does to the formula for the line. Whereas if you have to graph 3x, you know, graph 2x and see what happens, you know, you can only do so many. But if you are on the computer, you can drag that up and say, "Whoa, what's happening to that number? Why is it doing it?" (Jesse, Interview, 2/21/08).

The second concept that Jesse mentioned related to proofs of the Pythagorean Theorem. In the spring, Jesse’s full-time student teaching was going to be with a teacher, Mr. Grandy, who had participated in the first year of the Technology Partnership Project. In that year, the pre-service teachers had planned a unit on the Pythagorean Theorem that had used Geometer's Sketchpad in the instruction. Since then, Mr. Grandy had taught the lessons with other classes. Jesse had spoken with Mr. Grandy about this topic, and he looked forward to trying some of the ideas in during the student teaching practicum.

> Also with like, Geometer's Sketchpad and that kind of thing, um, hopefully in spring I will have a chance. I taught the Pythagorean Theorem pretty much without technology at the high school. But in the spring, I am going to be working at the middle school, and my cooperating teacher, really likes technology a lot it seems. And so he says, "Oh, I have a really great Geometer's Sketchpad way of doing this." And so it will be interesting to see how he does it with that (Jesse, Interview, 2/21/08).

Initially, Jesse held strong ideas that technology could be used for visualizing, but only after students had mastered the skills by hand. As he progressed in his coursework and the Technology Partnership Project, Jesse's ideas became more tentative. After the Technology Partnership Project, he was able to share specific examples of how *Visualizing with Technology* could be used for learning content.

Along with *Visualizing with Technology*, Jesse repeated other ideas that gave insight into his knowledge of students' learning mathematics with technology. Like Heather, Jesse also expressed ideas that showed how he thought students could move from concrete operations toward *Abstraction with Technology*. Jesse did not repeat these ideas as often as he did with other ideas, but *Abstraction with Technology* was present in his planning, teaching, and reflecting. During the Technology Partnership Project, Jesse expressed ideas that showed value in using technology to create abstract representations of the students' survey data. In reflecting on this teaching, he shared that *Abstraction with Technology* should have been a more important learning goal for the students.

In a team planning meeting, Heather shared ideas about how to teach students to format cells in Excel. She advocated that students should use formulas and cell names, not data values, to calculate percents, decimals and percents. This planning was described in detail in Heather's narrative and is not repeated here. In this exchange, Jesse agreed with Heather that using the abstract concepts of cell names and formulas was a good choice. He suggested that it would be good to have students use formulas and cell names because it was consistent with the worksheet that the students had used to learn graphing, *Practice with Excel* (Jesse, Plan, 2/05/08).

When Heather taught the lesson on formatting, students questioned the process of using formulas for such simple calculations and they wondered why Heather was asking them to go through such a complicated process to add four numbers. Heathers response to the student was, "Just bear with me. But you are right. You could just add them up by yourself. But I will show you why. It is coming" (Heather, Teach 2/6/08). Later in the lesson, Jesse stepped to the front of the room to address the students' concerns. Using Heather's data table, Jesse attempted to justify using abstract formulas.

> One of the things that is really cool about this—so looking at me really fast. So the reason that we had you put in "=this cell, plus this cell, plus this cell" is because now you are like, "Oh! When I took this data, instead of there being four people that like Ritz crackers. I forgot, there is two more people that like Ritz crackers." So, instead of four, there is actually 6. So, as soon as you type that in, it automatically changes the other ones for you. Okay, did you see that? I will do it again. Oh! There wasn't six, there was how many people? (Students shout numbers) There was 10! Here we go there was actually 10 people that like Ritz. It automatically changed these other things for you. And the total. Notice there is 16? If I added…there is 20 people that like Ritz, it is going to automatically add those for you there, so you don't have to add them up every single time. The software, Excel, will do it for you. Okay? Same with these. It will automatically format them after you do it once (Jesse, Teach, 2/6/08).

Jesse wanted the students to understand the value in making the spreadsheet dynamic. By using the technology to create formulas with variables, students were able to create a more powerful tool for data analysis—one that allowed for easy updates.

As Jesse reflected on the Technology Partnership Project, he thought about the way that his group had used technology to create abstract representations. He felt some students had learned from the process, but he also felt the abstract ideas could have been emphasized more.

> Like some of them got that out of it a little bit, just the fact that they typed the same things into these fields and they were able to change it. When you had these three things, but we didn't really emphasize that as much as I think we could have to really have that objective really more concrete with it (Jesse, Interview, 2/21/08).

Transitioning from concrete to abstract representations can be challenging for some students who struggle in mathematics. Jesse's group saw that technology could be used as a tool to facilitate this transition. In algebra, students commonly take concrete numbers from a data table and build abstract representations like graphs and equations. Jesse's ideas showed how he was using Excel to introduce these foundational algebraic ideas.

A third idea was repeated consistently by Jesse as he participated in the various research contexts. This repeating idea, *Motivation*, provided additional insight into Jesse's knowledge of students' learning mathematics with technology. When he thought about his own learning with technology, ideas about *Motivation* were common. In his teaching, Jesse tried to pass these motivating influences onto students. As he reflected on his teaching, Jesse offered *Motivation* as one of the primary justifications for using technology in the classroom.

In the Technology and Pedagogy course, Jesse used words like "cool," "magic," "fun," and "hook" when reflecting on different technology (Jesse, DB, 9/28/07, 10/9/07, & 10/28/07). Jesse shared personal feelings of enjoyment when using technology and talked openly about how accessible technology was in his home as a child. In a planning meeting, he told a story about how his parents used the computer as a reward to motivate him to do homework (Jesse, Plan, 2/8/08). In the interview Jesse shared the story again.

> And so, before I would go to school in the morning, I would hook up my Commodore 64 and play a few games of whatever and you know. That was kind of my reward for getting all of my homework done. And I would wake up early so I could do that. It was okay with my parents as long as I had everything done and prepared (Jesse, Interview, 2/21/08).

For Jesse, technology was a strong motivating factor in his learning. During his fall practicum and the Technology Partnership Project, Jesse observed situations where students expressed the same interest and *Motivation* to use technology. As he described these situations to his group, Jesse seemed encouraged by the students' motivation to use technology in their learning (Jesse, TechPed, 10/24/07; Plan, 2/12/08).

For Jesse, he saw that technology could motivate students in two ways. First, he shared that students were naturally drawn to technology because of its presence in their daily lives. He described how he had used this attraction to keep students engaged during a unit review lesson in his fall student teaching practicum. For that lesson, Jesse had built a PowerPoint presentation that mimicked a popular game show. He added the show's theme music and used PhotoShop to put his picture in the place of the show's host. By doing this, Jesse hoped to add a "personal touch" and to "grab the attention of the students and hook them into the game" (Jesse, DB, 10/9/07). In the interview, Jesse reflected on the role that the technology had played in engaging the students.

> …I think [there] is the kind of the wow factor...for example I have done a PowerPoint, *Who Wants to Be a Millionaire*. So, you know you can really get the attention of the students and it can be in day and age that we live, there is so much technology around all of them (Jesse, Interview, 2/21/08).

In addition to student engagement, Jesse described a second way that students were motivated by learning with technology. Jesse felt that technology helped students move beyond procedural skills in mathematics, motivating them to continue studying the subject.

> It's kind of similar to that where I think that it can help more advanced topics, instead of just having the students practice really basic things forever and ever and ever and get really bored and hate math. Versus, okay, you don't really understand, you kind of do this, you made a lot of errors, but let's go deeper in math where it is kind of more fun. And then after they have those ideas, "Oh, math can actually be fun!" Then they'll be more motivated to go back to learn their algebra and stuff (Jesse, Interview, 2/21/08).

Jesse ideas about *Motivation* from technology went beyond engagement in a particular lesson. Here, Jesse described technology as encouraging engagement in mathematics itself. He imagined that as students learn mathematics with technology, they were able to access mathematics that was "more fun" and this access had the potential to motivate them to continue learning.

Across the research contexts, Jesse shared ideas that gave insight into his knowledge of students' learning mathematics with technology. He repeatedly expressed ideas that showed how students could *Visualize with Technology* through graphing tools and geometric representations. He used Excel to help students begin to move towards *Abstraction with Technology*. Finally, his ideas on the *Motivation* of students as they learned with technology focused on both lesson engagement and interest in mathematics as a whole. Taken together, these three repeating ideas illustrated Jesse’s knowledge of students’ learning mathematics with technology.

Research Question One

In Chapter Two: Review of the Literature, the Learning to Teach with Technology Framework was introduced. This framework was built from a synthesis of literature on teaching and learning. Specifically, pre-service teacher learning was examined with a situated perspective on learning and three domains of professional expertise were explored: Professional Identity, Technology Specific Pedagogy, and Content Knowledge (Peressini et al., 2004). Technology Specific Pedagogy was the domain identified as the focus for this study. To better understand the elements of Technology Specific Pedagogy, research questions were developed to investigate both the social and psychological perspectives of pre-service teachers as they learned to teach with technology. Table 4.5 shows how each perspective was characterized.

Table 4.5: The Focus of the Study

The Focus of this Study		
Domain of Professional Expertise	**Social Perspective**	**Psychological Perspective**
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Pre-service teacher’s overarching conception of teaching mathematics with technology
		Pre-service teacher’s knowledge of student understandings, thinking, and learning mathematics with technology

The first research question examined elements of the social perspective: Norms of Pedagogical Reasoning about Technology. This question asked: What patterns of participation are displayed across learning contexts as pre-service teachers reason pedagogically about teaching mathematics with technology prior to their full-time student teaching?

For the purposes of this study, the researcher defined patterns of participation as repeating ideas that occurred in three or more of the research contexts. For example, Amy referenced the idea of *Playing to Learn* in four contexts, (1) the Technology and Pedagogy course discussion board, (2) her teaching, (3) her interview, and (4) her lesson plans. Taken together, these repeating ideas that appeared across the four contexts displayed a pattern of participation: *Playing to Learn*. In contrast, Heather spoke about issues of *Equitable Access* during one planning meeting (Heather, Plan, 2/8/08). However, this idea was not repeated in any other research context so it was not classified as a pattern of participation. Amy, Jesse, and Heather displayed four patterns of participation as they reasoned pedagogically across the research contexts: (1) *Playing to Learn*, (2) *Lesson Design*, (3) *Student Control*, and (4) *Equitable Access*.

Playing to Learn

All three of the pre-service teachers described in the case studies displayed the repeating idea of *Playing to Learn* in three or more of the research contexts. Each pre-service teacher had a pattern of participation that differed from the others. However, their ideas centered on the understanding that when teaching with technology, students should be given time for open inquiry as they learned to use new tools.

For Amy, her ideas about *Playing to Learn* were impacted by her experiences in the Technology Partnership Project. Initially, Amy described open inquiry as useful in her own learning. She described this pedagogical strategy as a way for students to have more fun and to really learn to use the tools. During the Technology Partnership Project, Amy used a structured worksheet as a way to teach students to use Excel. In spite of this structure, Amy's language during teaching encouraged students to use play as a way to learn to graph with Excel. After the Technology Partnership Project, Amy was able to identify ways that the structured worksheet had restricted students' learning. Her experiences in the Technology Partnership Project had given her concrete experience that reinforced her prior understanding of effective teaching with technology.

Initially, Heather was skeptical of the benefits of *Playing to Learn* and she found it frustrating for her own learning during the Technology and Pedagogy course. During the Technology Partnership Project, Jesse convinced the group that *Playing to Learn* was the best way to teach students to graph with Excel. Heather accepted his idea, and carried it out in her own instruction as she worked with individual students. As she reflected on the Technology Partnership Project experience, she was able to identify benefits of the pedagogical strategy of *Playing to Learn* and she could identify ways that she had used it in her own learning. For Heather, the Technology Partnership Project facilitated a change in her understanding of how to teach students using technology. Through her negotiation with Jesse and her own teaching with this strategy, she was able to appreciate the value of *Playing to Learn*.

Jesse's ideas about *Playing to Learn* were strong at the beginning of the Technology Partnership Project. He found value in this strategy for his own learning and could imagine its usefulness for students. During the Technology Partnership Project, Jesse advocated for using *Playing to Learn* as the best way to teach graphing and he convinced his group to try out this idea. He was also able to develop and teach a lesson that used the strategy, just as he had suggested during the planning meeting. Jesse's initial ideas were reinforced by this experience. After the Technology Partnership Project, he described *Playing to Learn* as the best way to teach students to use new technology in mathematics. For Jesse, the Technology Partnership Project gave him an opportunity to advocate for his ideas with a peer group. He was also able to validate his ideas about teaching with technology in the context of the classroom. In the end, his pedagogical reasoning about teaching with technology was confirmed.

For Amy, Heather, and Jesse, *Playing to Learn* was an important part of their pedagogical reasoning about technology. By examining their learning across the various research contexts, this reasoning was clearly characterized. During the

Technology and Pedagogy course, all three pre-service teachers shared their prior understandings about the value of *Playing to Learn*. The Technology Partnership Project served as a way for these understandings to be tested.

Lesson Design

Amy, Heather, and Jesse all expressed repeating ideas related to *Lesson Design* in three or more of the research contexts. *Lesson Design* related to the form of structure and level of structure that took place in a lesson as a teacher taught mathematics with technology. The patterns of participation were different for each of the three pre-service teachers as they learned to teach with technology in the various research contexts. Each pre-service teacher held prior understandings of the amount of lesson structure, and the form that this structure should take when teaching with technology. These understandings were tested and in some cases revised based on the pre-service teachers' experiences in the Technology Partnership Project.

In the Technology and Pedagogy course, Amy shared strong feelings that worksheet support and follow-up instruction should be included whenever someone taught with technology. In her own teaching during the Technology Partnership Project, Amy designed lessons consistent with this theme. She provided worksheets for students that guided them through graphing with Excel. She also led large-group demonstrations that combined all the ideas from the individual exploration of the graphing software. However, as she reflected on these lessons, Amy identified ways that the students' learning had been restricted through her chosen *Lesson Design*. For Amy, the Technology Partnership Project gave her an opportunity to test her ideas in the context of a classroom. This test caused Amy to revise her thinking and to consider ways that *Lesson Design* might inhibit student learning.

Heather also held strong prior ideas about the importance of structured *Lesson Design*. In the Technology and Pedagogy course, she identified structured worksheets as a way to facilitate student learning. In the Technology Partnership Project, Heather's group provided the students with a worksheet to guide them through the basic features of Excel. In one planning meeting, Heather advocated for leading students through a large group demonstration on formatting numbers and her group agreed with this idea. After teaching these lessons, Heather reflected on the way they helped students to learn. Her focus turned to how the structure had helped her as a teacher and how it might have helped students who were English Language Learners (ELL). For Heather, the Technology Partnership Project gave her an opportunity to advocate for her ideas about *Lesson Design* with her peers. It also gave her an opportunity to test those ideas with students in her own teaching. After this lesson, her perception of the importance of *Lesson Design* focused on herself as a teacher, and on specific students who were helped by this pedagogical strategy.

As Jesse participated across the various research contexts, *Lesson Design* did not seem to be a strong focus of his thinking. He spoke briefly of it on the Technology and Pedagogy discussion board, sharing how the structure of some of the lessons had helped him to learn. During the Technology Partnership Project, Jesse used a structured worksheet to teach the basic functions of Excel. He also agreed with Heather when she advocated for a structured demonstration of formatting cells in Excel. However, Jesse did not share ideas about *Lesson Design* as he reflected on his teaching. Of the three, Jesse showed the strongest commitment to open inquiry as the best way to teach with technology. Perhaps for Jesse, open inquiry was the way he imagined *Lesson Design*.

Student Control

Two additional patterns emerged as the pre-service teachers participated in the various research contexts. In contrast to *Playing to Learn* and *Lesson Design*, these patterns were not displayed by all three pre-service teachers described in the cases. The third pattern that emerged from the data was only seen in Heather's repeating ideas as she participated in the research contexts. This idea, *Student Control*, referenced the level with which the student, as opposed to the teacher, controlled the technology during learning.

In the Technology and Pedagogy course, Heather did not share any ideas related to *Student Control*. However, in the context of the Technology Partnership Project, Heather had the opportunity to work with actual students who were learning mathematics with technology. As she led a large group demonstration on formatting cells in Excel, Heather started the demonstration by controlling the technology. When the technology did not perform as she had planned, she quickly changed to a *Student Control* strategy and taught this way consistently throughout the remainder of the Technology Partnership Project. In one planning meeting, Heather spoke openly of her struggles with and also her commitment to the idea of *Student Control*. For Heather, the Technology Partnership Project facilitated the emergence of her ideas about who should control the tool during mathematics lessons that use technology. When her plans did not meet her expectations, Heather's ideas about *Student Control* were one strategy she called upon in her adjustments.

It is unclear why the idea of *Student Control* did not surface as Amy and Jesse participated in the various research contexts. The pedagogical decision of who controls the technology during learning was not discussed during the Technology and Pedagogy course, so perhaps Amy and Jesse had not considered it. Both Jesse and Amy showed examples in their teaching where students controlled the technology and where the teacher controlled the technology. Further investigation into their ideas about *Student Control* would be desirable.

Equitable Access

A fourth, and final, pattern developed from Jesse's ideas as he participated in the different research contexts. This idea, *Equitable Access*, was not demonstrated in the ideas of Heather or Amy. *Equitable Access* was the idea that students are entitled to equivalent learning opportunities at school regardless of their background or level of academic achievement.

Jesse expressed strong ideas about *Equitable Access* when he reflected on his experiences in the Technology and Pedagogy course. He acknowledged that not all students had technology available in their personal lives, so he saw school as a possible way to provide students with opportunities to use different technology tools. During planning and teaching in the Technology Partnership Project, Jesse inquired about the students' level of technology access. He spoke with the in-service teacher and individual students to assess the amount of resources available to students at the middle school. As he reflected on his experience, Jesse's ideas about *Equitable Access* expanded. In his interview, he spoke of the need to provide students with access to technology tools. In addition, he saw technology as a way to facilitate access to higher level mathematics for students who struggled with computational fluency. The Technology Partnership Project gave Jesse an opportunity to connect real students to his ideas about *Equitable Access*. This experience also enabled him to see how this access could also have a powerful impact on student learning.

For Heather and Amy, *Equitable Access* did not surface as a repeating idea during their participation in the different research contexts. However, in one planning meeting, Heather spoke of how she was encouraged to see the way the ELL students in the class were so successful at using the technology (Heather, Planning, 2/8/08). *Equitable Access* had been an issue for Heather as she was growing up. In team planning and in her interview, Heather spoke openly of how school was the only way she could have access to Internet resources. It is unclear why access was not a more outwardly displayed issue for Heather.

In her work, Amy shared ideas about the importance of students having mastery of hand calculations before they could move on to technology applications. She demonstrated repeating ideas consistent with the understanding that technology was a tool for extending learning, not a tool for facilitating it. Her ideas that technology was a "bonus" might have prevented Amy from seeing *Equitable Access* as important to her pedagogical reasoning.

Summary

Across the three case studies, four patterns of participation developed as the pre-service teachers reasoned about teaching with technology. *Playing to Learn* and *Lesson Design* were seen in the ideas of Amy, Heather, and Jesse.

Unique to Heather was the idea of *Student Control*. Likewise, Jesse was the only one who shared ideas about *Equitable Access* in more than one context. Taken together, these four patterns provided insight into the ways that pre-service teachers reasoned about their pedagogical choices.

As pedagogical reasoning becomes normative within a group, a better understanding of the social perspective of Technology Specific Pedagogy becomes clearer. However, truly characterizing this domain of professional expertise requires looking at the pre-service teachers' learning through a psychological perspective as well. The emergent perspective acknowledges that the social aspects and psychological aspects of learning are reflexive and continually impact and overlap each other (Cobb & Yackel, 1996). The remainder of this chapter examines the learning of the pre-service teachers from the psychological plane.

Research Question Two: Part I

In her work, Niess (2005) described the knowledge needed to teach with technology, Technology Pedagogical Content Knowledge (TPCK), as having four components. Of these components, two were used in Chapter Two: Review of the Literature to define the psychological perspective of Technology Specific Pedagogy. The second research question in this study focused on illuminating Technology Specific Pedagogy from the psychological perspective. Specifically, this question asked: In what ways do the Technology Partnership Project and its features facilitate pre-service mathematics teachers' development of TPCK? To answer this question, two sub-questions were presented that focused on individual components of TPCK. First, how does this model contribute to pre-service teachers' overarching conception of teaching mathematics with technology?

Doing Technology versus Using Technology

As the pre-service teachers participated in coursework, the Technology Partnership Project, and interviews, they shared ideas that illustrated their overarching conception of teaching mathematics with technology. One element of this conception was seen in the way that the pre-service teachers talked about the technology-infused activities. Some ideas were consistent with the general sense of *Doing the Technology*, e.g. "doing Excel." Other ideas were more consistent with the general sense of *Using the Technology* to teach mathematics. In all three interviews, the case participants shared ideas that called upon their experiences in the Technology Partnership Project to describe the benefits *Using the Technology*. For Amy, Heather, and Jesse, the Technology Partnership Project was an experience that caused them to reflect on the benefits and drawbacks of "doing" versus "using" technology in their teaching.

Amy did not share any ideas about *Doing Technology* in the Technology and Pedagogy course. This idea was not an issue that the instructor, Mr. Compton, addressed in his course. For Amy, the Technology Partnership Project was the first time in the study where she expressed ideas that indicated her understanding of *Doing* versus *Using Technology*. Throughout the planning meetings and her instruction, Amy regularly shared the idea that the students were "doing Excel." As she reflected on the Technology Partnership Project, Amy shared sadness that her students did not seem to have learned what she had hoped as a result of the lessons. She felt that they did not appreciate the power and potential of Excel. After her experience with the Technology Partnership Project, Amy began to question the effectiveness of *Doing Technology* with students. Her stance on *Doing Technology* seemed more tentative after her experiences in the Technology Partnership Project, and follow-up activities explicitly connected to the Technology Partnership Project might have influenced her conception even more.

Like Amy, Heather's ideas about *Doing Technology* versus *Using Technology* first surfaced during the Technology Partnership Project. In her planning, Heather focused on teaching mathematical objectives by *Using Technology*. As she taught, Heather's language was also consistent with the idea that the students should be using the technology as tools to learn the mathematics. However, as she reflected on the Technology Partnership Project, Heather shared frustrations that the lesson objectives had changed during teaching and focused too much on the technology and not enough on the content. It is unclear why this change of focus occurred. In spite of this, he Technology Partnership Project gave

Heather a context to try to teach *Using Technology* and it gave her insight into the challenges that teachers face as they teach mathematics with technology.

In the Technology and Pedagogy course, Jesse acknowledged a difference between knowing how to use technology and knowing how to teach with technology. Like Heather and Amy, Jesse first addressed the idea of *Doing* or *Using Technology* during the Technology Partnership Project. His lesson plans and his instructional strategies used language consistent with the idea of *Using Technology* as a tool for learning mathematics. However, like Heather, he shared frustrations with how the idea of *Using the Technology* was carried out in Technology Partnership Project. In his interview, Jesse said that while the unit objectives had changed into a focus on the technology, he acknowledged this change of focus was not desirable. He shared firm convictions that students should be *Using Technology* to learn mathematics. During the Technology Partnership Project, Jesse experienced difficulty in designing lessons that used technology to teach mathematics. In spite of this difficulty, his conception of teaching with technology was reinforced when he reflected during the individual interview.

Simplify/Extend vs. Enhance/Differentiate

Another element of the pre-service teachers' overarching conception of teaching mathematics with technology can be seen in the way that they described the role of technology in a mathematics classroom. For Amy, the purpose of technology was to simplify calculations and to provide extension activities for students once skills had been mastered by hand. In contrast, Heather and Jesse described the role of technology as a way to enhance and differentiate mathematics instruction. For all three, the Technology Partnership Project was an opportunity to enact these roles in an actual classroom.

In the Technology and Pedagogy course, Amy explained that technology should be used to simplify calculations. She also shared firm convictions that skills should be mastered by hand before technology was used. In the Technology Partnership Project, the in-service teacher, Ms. Sanders, advocated for teaching graphing with Excel rather than by hand. Amy agreed with this idea and was willing to test it during instruction. While she was teaching, Amy used the idea of *Technology as Simplifier* to entice students into learning to use Excel. She did allow the students to graph with the technology, but *Technology as Extension* was observed through the importance her group placed on hand calculations of percents. As she reflected on the Technology Partnership Project, Heather identified technology as a way to enhance, rather than just extend or simplify instruction. For Amy, the Technology Partnership Project was an opportunity to work with an experienced teacher who had a different overarching conception of teaching mathematics with technology. This opportunity pushed Amy to try a different approach and after the experience she was able to describe the benefits of using *Technology as Enhancer*.

During the Technology and Pedagogy course, Heather did not share any ideas that addressed the role of technology in teaching mathematics. As she planned lessons for the Technology Partnership Project, Heather designed activities that used Excel to teach graphing and calculations of fractions, decimals, and percents. Her work in these lessons showed a conception of *Technology as Enhancer* of mathematics teaching. As she reflected on the students' learning during the unit, Heather felt that because of the technology tools, students had a context from which to draw as they learned the procedures for calculating percents and that this experience enhanced the way they learned these skills. The Technology Partnership Project was an opportunity for Heather to design lessons consistent with her overarching conception of teaching mathematics with technology. Because of this experience, Heather had a way to see how this conception influenced student learning.

Jesse's overarching conception of teaching with technology also began to surface during the Technology Partnership Project. In the planning of the lessons, Jesse advocated that students have choices in their learning and that technology allowed for a differentiated final product. Jesse also suggested alternate assignments for students who were not progressing during the unit. This view of *Technology for Differentiation* was unique to Jesse. As he reflected on the role the technology in the Technology Partnership Project unit, Jesse described the technology as facilitating a unique experience for each student. For Jesse, the Technology Partnership Project gave him way to use his knowledge of technology to differentiate instruction for students with a wide range of abilities.

Research Question Two: Part II

The Technology Partnership Project also contributed to the pre-service teachers' development of a second aspect of TPCK. The second part of research question two investigated this development. Specifically, this question asked how this model contributed to pre-service teachers' knowledge of students' understandings, thinking, and learning in mathematics with technology. For Amy, Heather, and Jesse, the Technology Partnership Project contributed to their thinking in three ways. First, all three pre-service teachers expressed ideas about how students could learn by *Visualizing with Technology*. Second, Heather, and Jesse designed lessons that helped students learn by *Abstraction with Technology*. Third, for all three, *Motivation* was an important way that the students' learning was impacted by the technology tools.

Visualizing with Technology

One way that students can learn mathematics is by interacting with visual models using technology. Examples of technology that affords access to visual representations are spreadsheets, graphing calculators, and Geometer's Sketchpad. Initially, all three pre-service teachers shared ideas that graphing with technology was beneficial only after students had graphed by hand. During the Technology Partnership Project, the pre-service teachers all taught lessons that represented an alternate idea: using technology to introduce graphing concepts. As Amy, Heather, and Jesse reflected on the students' learning, the pre-service teachers' ideas shifted towards a view that *Visualizing with Technology* might be a way for students to learn mathematics.

Amy's reflections during the Technology and Pedagogy course demonstrated the idea that students should learn to graph with technology after they had mastered graphing by hand. Amy did acknowledge benefits to visualizing geometry concepts with Geometer's Sketchpad, but her ideas about how students learned by *Visualizing with Technology* were narrow in scope. In the Technology Partnership Project, Ms. Sanders advocated for teaching graphing with Excel in a way that conflicted with Amy's prior understandings. After this experience, Amy was able to imagine more ways that students could learn using technology. The group planning component of the Technology Partnership Project gave Amy an opportunity to try someone else's ideas and to learn from these ideas.

In the Technology and Pedagogy course, Heather's work showed that she thought technology could be used to teach graphing and to help students visualize mathematical concepts. During the project, she advocated for teaching a lesson that used technology to see how fraction, decimal, and percent calculations were similar. In her interview, Heather shared that she felt this lesson would help students learn procedural skills later. For Heather, the Technology Partnership Project was a chance for her to advocate for her ideas to a peer group and to convince the group of the validity of the ideas. As a result, her ideas were confirmed as she reflected on the students' learning.

Jesse's stance on *Visualizing with Technology* was tentative during the Technology and Pedagogy course. Initially, he shared strong feelings that graphing with technology should only happen after hand graphing was learned. As he discussed the issue with Mr. Compton, he began to express ideas that maybe there was a different way to think about *Visualizing with Technology*. During the Technology Partnership Project planning, Jesse advocated for teaching the students to graph with Excel. He designed a graphing challenge activity that he taught during the unit. As he reflected on the students' learning, Jesse was able to identify multiple ways that students could learn mathematics using technology tools to visualize concepts. The Technology Partnership Project gave Jesse a context where he could advocate for his ideas with a group of peers, test those ideas, and reflect on their success. After the project, Jesse showed a broader knowledge of how students learned through *Visualizing with Technology*.

Abstraction with Technology

Technology can also be used to help students create abstract representations of concrete ideas. For example, Excel allows for data values to be represented as cell values (variables) and used in formulas to perform calculations. For Heather, the use of dynamic spreadsheets was one way to help students move toward *Abstraction with Technology*. Jesse also shared some ideas that were consistent with this understanding.

Heather's prior experience from the technology prerequisite course enabled her to imagine ways that dynamic spreadsheets could help students to learn abstract mathematical concepts. During the Technology Partnership Project planning meetings, Heather advocated for the use of dynamic spreadsheets as a way to learn about converting fractions, decimals, and percents. After teaching the students to create these spreadsheets, Heather reflected that this lesson provided an important foundation for students to learn to calculate by hand. For Heather, the Technology Partnership Project gave her an opportunity to advocate for a teaching strategy that was based on her prior knowledge of students' learning mathematics with technology. After convincing her peers of the benefits of dynamic spreadsheets, she was able to test her ideas through teaching and reflection.

Jesse did not share any prior knowledge of using technology in learning to create abstract representations. However, during the planning meetings for the Technology Partnership Project, Jesse agreed with Heather about her ideas for teaching students to create dynamic spreadsheets. During the instruction, Jesse took time with the whole class to show how dynamic spreadsheets were easily updated. Jesse aimed to show the students the benefits of *Abstraction with Technology*. As he reflected on the students' learning, Jesse was unsure of how many students really understood the abstract concepts of formulas and cell values. He shared that he saw *Abstraction with Technology* as something he wished he had emphasized more in his teaching. For Jesse, the Technology Partnership Project gave him an opportunity to try ideas that were not his own, and to reflect on the success of those ideas.

It is unclear from the available data why Amy did not share any ideas related to *Abstraction with Technology*. Dynamic spreadsheets and other ways to teach about abstract concepts with technology were not discussed in the Technology and Pedagogy course. Heather and Jesse's experiences were initiated by Heather's prior knowledge. During the Technology Partnership Project, the two teaching teams did not interact to share planning ideas. Perhaps if Amy had been able to share in the planning activities with Heather's group, she would have been able develop ideas about how students could learn abstract mathematical concepts with technology.

Motivation

A final repeating idea appeared in the work of all of the cases in this study. *Motivation* was seen by all three pre-service teachers as a way to impact students' learning with technology. For Amy, Heather, and Jesse, the Technology Partnership Project provided evidence of the role that *Motivation* played in promoting student engagement in individual lessons and in mathematics as a whole.

Amy's prior experiences did not include technology as a way to motivate her, but she imagined technology like Geometer's Sketchpad would have helped her to enjoy geometry more. As she taught in the Technology Partnership Project, Heather used the idea of *Technology as a Simplifier* to motivate reluctant learners to explore Excel. When she reflected on her teaching, she shared that the technology had made the lesson fun and cool. Amy's own history as a learner did not include opportunities to see technology as a motivating influence, but the Technology Partnership Project allowed her to witness examples of the *Motivation* from using technology in learning.

During the Technology and Pedagogy course, Heather imagined that technology could be a tool for *Motivation* and encouraging student engagement. As she taught in the Technology Partnership Project, Heather's language and teaching style were not consistent with this prior understanding. As she reflected on the students' learning, she acknowledged that *Motivation* had not played the role that she would have predicted, yet she still shared ideas that using technology to motivate students was important for their learning. The Technology Partnership Project caused Heather to reconsider the role of *Motivation* in students' learning mathematics with technology and to question the ways that she used it in her own teaching.

For Jesse, *Motivation* played an important role in his own teaching and learning in the past. In his writing, Jesse described designing a PowerPoint presentation to motivate students to study for a chapter test during his fall practicum. During the Technology Partnership Project, Jesse was encouraged to see how students were motivated to learn to use video and PowerPoint in their own projects. He also expressed pleasure when students wanted to know more about how the laptops worked. In his interview, Jesse's expressed an expanded knowledge of the role of *Motivation* in students' learning. He described ways that technology motivated students to engage in the lesson and to want to learn more about mathematics. The Technology Partnership Project gave Jesse an opportunity to see a richer picture of how students were motivated to learn mathematics while using technology.

Question Two: Summary

The pre-service teachers in this study had a variety of contexts where they learned to teach with technology during their licensure program. A number of these contexts took place during the Technology Partnership Project. After examining the data, ways that Technology Partnership Project and its features facilitated pre-service mathematics teachers' development TPCK (Research Question 2) can be identified. For these pre-service teachers, the Technology Partnership Project provided:

- Concrete examples to challenge or reinforce their prior understanding of teaching with technology
- Opportunities to work with an experienced teacher in planning and executing a lesson

- Opportunities to advocate for their own ideas and convince others of the validity of those ideas
- Opportunities to teach using the ideas of their peers and the in-service teachers and to learn from those ideas
- A way to connect preconceptions about the way students learn with actual examples of student learning
- An occasion to see students learning in a different way from their own experiences as a learner
- An experience of designing a technology-infused lesson and then implementing that lesson in an authentic environment

For all three students, the Technology Partnership Project provided an opportunity to test ideas and reflect on whether students should *do technology* or *use technology to do mathematics*. The Technology Partnership Project was one catalyst for this thinking as these ideas were not addressed during their Technology and Pedagogy I course. For Amy, her experiences in the Technology Partnership Project enabled a shift in her thinking as she questioned the benefits of *Doing the Technology*. The Technology Partnership Project helped Jesse and Heather to appreciate the complexity of designing lessons that taught mathematics with technology. Overall, the opportunity to design and teach actual lessons helped the pre-service teachers develop their thinking about teaching with technology in the mathematics classroom.

The Technology Partnership Project also engaged and developed the pre-service teachers thinking about the purpose of teaching mathematics with technology. Prior to the Technology Partnership Project, Amy saw technology as a tool for simplifying or extending learning. The project was a way for her to experiment with a new way of thinking. Because the lessons were planned by the group, Amy compromised in response to Ms. Sanders' suggestion that graphing should be taught first with Excel. This opportunity to work with an experienced teacher to design and teach lessons enabled Amy to develop her overarching conception of teaching with technology.

The field experience component of the Technology Partnership Project provided Jesse and Heather opportunities to test their ideas about enhancing and differencing instruction in an authentic context. Both of them had prior understanding about the purpose of teaching with technology. The context of team teaching provided an experience with advocating and defending their pedagogical choices within their team. They were also given a context to teach using pedagogical ideas that were not their own. In the spirit of collaborative harmony, the pre-service teachers had to make compromises. In some cases, these compromises enabled them to see the benefits of alternate conceptions of the role of technology in the mathematics classroom.

Amy, Heather, and Jesse all shared that their own experiences learning mathematics prior to graduate school had not included much time learning with technology. All three had preconceptions about students' learning mathematics with technology. For all of them, the Technology Partnership Project offered a way for these pre-service teachers to see students *Visualizing with Technology* and moving towards *Abstraction with Technology*. The Technology Partnership Project also gave them concrete examples of the role of *Motivation* when students learned with technology. For Amy and Heather, they were able to see students as motivated to engage in a particular lesson. For Jesse, the Technology Partnership Project showed him how students might be motivated to learn more about mathematics as a whole.

Effective teaching with technology was described in the first chapter as including a number of characteristics. These characteristics were classified by Niess (2005) as the four components of TPCK. The ideas expressed by Amy, Heather, and Jesse developed as they learned in the various contexts of their licensure program. These developing ideas demonstrated a change in their ability to effectively integrate technology into their instruction, thus in the development of their TPCK.

Teachers who effectively integrate technology in teaching mathematics have developed a rich knowledge base and firm beliefs about the role of technology in teaching mathematics. For these teachers, mathematics lessons are designed to meet content objectives and the purpose of the technology tool is to facilitate student learning (Pierson, 2001). These teachers know that instruction should go beyond *Doing the Technology* and should include *Using the Technology* to teach mathematics. Although all three participants in this study began with different overarching conceptions, each showed development toward *Using the Technology* to teach mathematics.

In these ideal classrooms, technology is used thoughtfully, selectively, and regularly. *Technology as Enhancer* and *Technology for Differentiation* are two ways to characterize how this might look in practice. Even though Amy began with ideas about *Technology as Extension* and *Technology as Simplifier*, she still showed development in her thinking as she learned across the research contexts.

Teachers who effectively integrate technology into instruction also have a rich understanding of how technology can impact the way students learn mathematics. These teachers recognize the potential that technology has for assisting students to visualize mathematical concepts, make connections between mathematical representations, and develop their abstract thinking (Bakker & Frederickson, 2005). As Amy, Heather, and Jesse developed their thinking about *Visualizing with Technology* and *Abstraction with Technology*, they developed this component of TPCK. Teachers who effectively integrate technology also recognize the motivating factor that technology can have on student engagement and interest in the subject of mathematics (Vincent, 2005). All three participants developed ideas consistent with the theme of *Motivation*. These ideas were further evidence of their development of their knowledge of students' thinking, learning, and understanding of mathematics with technology.

CHAPTER FIVE

DISCUSSION

> Another thing that I have realized with working with technology this term is that I may know how to use the technology myself, but it doesn't mean I can teach with it. So, that's a goal of mine, to have more ideas when someone says, "What would you teach with technology? What wouldn't you teach?" (Heather, Interview, 2/21/08)

The purpose of this study was to capture and describe the learning and understandings of pre-service teachers as they participated in the Technology Partnership Project embedded in their teacher preparation program. Specifically, the pre-service teachers' development of Technology Specific Pedagogy was the primary focus. Table 5.1 illustrates how Technology Specific Pedagogy was defined in Chapter Two: Review of the Literature.

Table 5.1: The Focus of this Study

Domain of Professional Expertise	**Social Perspective**	**Psychological Perspective**
Technology Specific Pedagogy	Norms of Pedagogical Reasoning about Technology	Pre-service teacher's overarching conception of teaching mathematics with technology
		Pre-service teacher's knowledge of student understandings, thinking, and learning mathematics with technology

In alignment with this focus, research questions were developed to investigate the pre-service teachers' learning from both social and psychological perspectives.

The first research question focused on the social perspective of Technology Specific Pedagogy. Specifically, what patterns of participation were displayed across learning contexts as pre-service teachers reasoned pedagogically about teaching mathematics with technology prior to their full-time student teaching? Examination of the data from the social perspective revealed four patterns of participation that were consistent with the theme of pedagogical reasoning about teaching with technology. These patterns were: *Playing to Learn*, *Lesson Design*, *Student Control*, and *Equitable Access*.

The second research question addressed the pre-service teachers' development of Technology Specific Pedagogy from a psychological perspective. This question asked, Does the Technology Partnership Project and its features facilitate pre-service mathematics teachers' development of Technology Pedagogical Content Knowledge (TPCK)? There are four components of TPCK, and this study revealed that the pre-service teachers developed in two of these areas. Examination of the data from the psychological perspective revealed six repeating ideas illustrating the pre-service teachers overarching conception of teaching mathematics with technology: *Technology as an Extension*, *Technology as a Simplifier*, *Doing the Technology*, *Technology as an Enhancer*, *Technology for Differentiation*, and *Using the Technology*. The data analysis also revealed three repeating ideas illustrating the pre-service teachers' knowledge of students' thinking, learning and understanding of mathematics with technology: *Visualizing with Technology*, *Abstraction with Technology*, and *Motivation*.

Synthesis of Results

The literature calls for teacher preparation programs and professional developers to help teachers become technology integrationists, "...teachers possessing the unique ability to understand, consider, and choose to use technologies *only* when they uniquely enhance the curriculum, instruction and students' learning" (Hughes, 2004, p. 346). Asking teachers to integrate technology into their mathematics instruction means that to teach with technology must begin during the initial licensure program (Angeli & Valanides, 2005). Part of this preparation includes time and opportunities for pre-service teachers to develop norms of pedagogical reasoning about teaching with technology. Negotiation of norms can be prompted by a variety of activities including: new experiences, observation of learning cases, discrepant events, and individual reflection (McNeal & Simon, 2000). In this study, the Technology Partnership Project facilitated unique opportunities for the pre-service teachers to engage in developing the knowledge needed to teach with technology.

All three pre-service teachers in this study had used technology for instructional delivery (interactive whiteboards, PowerPoint presentations) prior to the Technology Partnership Project, but designing lessons where students used technology to learn mathematics was a new experience for them. During the Technology Partnership Project, the pre-service teachers were able to observe cases of students learning with technology. Interacting with students allowed Jesse to gain a broader understanding of *Equitable Access* that included not just access to technology, but also access to higher mathematics. These interactions also helped Heather to confirm her ideas about the importance of *Student Control*. In some cases, observations of students learning conflicted with the pre-service teachers' prior understandings about teaching with technology. For Amy, these discrepant events led to a change in the way she viewed the role of structure in *Lesson Design*. Heather's observations of students' learning left her with new insights into the benefits of *Playing to Learn*.

These patterns of participation are not unique to the ideas of the pre-service teachers in this study. Others have discussed and debated the role of play, lesson structure, and student control in teaching with technology (Clements & Sarama, 2005; Hollebrands & Zbiek, 2004). The importance of equity and access can also be found in the National Educational Technology Standards for Teachers (NETS-T) (ISTE, 2003). However, of importance is that these ideas emerged as a result of the various learning activities in the teacher licensure program. These learning activities prompted the pre-service teachers to develop ideas, negotiate the ideas with a group, test the ideas in their own teaching, and reflect on the viability of the ideas. When this process occurs in a social setting like the Technology Partnership Project, the impact on pre-service teachers pedagogical decisions is noteworthy because it can actually lead to a change in teaching practice (Park & Ertmer, 2008).

Another important part of teacher preparation should include time and opportunities for pre-service teachers to develop the knowledge needed to teach with technology (Niess, 2005). This knowledge, TPCK, includes an overarching conception of teaching with technology and knowledge of students' thinking, learning and understanding of mathematics with technology. During the Technology Partnership Project, pre-service teachers also expressed ideas that were consistent with these two components of TPCK.

In part, the overarching conceptions of the pre-service teachers in this study ranged from *Doing the Technology* to *Using the Technology*. A pre-service teacher's experiences as a learner can determine his or her own personal definition of technology integration. This personal definition of technology integration impacts the way teachers plan technology lessons, teach with technology, and manage resources in the classroom (Pierson, 2001). For Amy, her knowledge of technology was not as strong and she had few experiences as a learner from which she could draw. Amy viewed technology as something that students should "do" during mathematics class. For Heather and Jesse, their knowledge of technology was stronger and they had richer prior experiences using technology in their own lives. Heather and Jesse viewed technology as a tool for learning mathematics. Characterizing the overarching conceptions of these pre-service teachers is more complex than just saying, "Teachers teach how they learned." Rather, the past experiences of the pre-service teachers, along with their own knowledge base and learning style, impacted their overarching conception of teaching with technology.

Another aspect of the overarching conceptions of the participants in this study ranged from *Technology as a Simplifier/Extension* to *Technology as an Enhancer/Differentiator*. These ideas are consistent with other views expressed in literature of technology as a way to *amplify* learning (computers do things the human brain cannot do like complex calculations) and technology as a way to *augment* learning (computers shape the way humans learn with the tool) (Angeli, 2008). Hughes (2005) describes three categories for classifying teachers' overarching conception of teaching mathematics with technology.

1. Technology as replacement—technology-based activities replace other activities, but the tool does not change instruction, student learning or content goals
2. Technology as amplification—technology based activities include the same tasks as traditional lessons, but the new activities are more efficient and effective
3. Technology as transformation—technology changes the learning process, content, cognitive processes, problem solving, and instructional practices

Hughes argues that effective technology integration requires a shift in conception from technology as replacement to technology as transformation. The data in this study indicated that the pre-service teachers were making this shift in light of their experiences with the Technology Partnership Project. At the end of the project, Amy was able to identify ways that technology could transform the learning of the students. In their interviews, Heather and Jesse were able to cite specific examples of how the technology had transformed the learning.

As the participants in this study developed their knowledge needed to teach with technology, they expressed ideas that gave insight into what they understood about the way students think and learn mathematics with technology. Three ideas emerged: *Visualizing with Technology*, *Abstraction with Technology*, and *Motivation*. All three of the pre-service teachers were able to identify the how technology could create visual representations to aid students in learnin mathematical concepts. Heather, Jesse, and Amy also identified ways that technology motivates students to engage in the lesson and in mathematics as a whole. For Heather, the power of technology to represent abstract ideas was clear and she was able to share this knowledge with Jesse during the Technology Partnership Project.

Technology can facilitate "conceptual conversations" between learners, conversations that are based on relationships and explanations and not on procedures (Knuth & Hartmann, 2005). For example, Amy recognized that students could answer a wide range of questions about the trash audit data by using the graphs they had built with Excel. The discussion on the final day of the unit focused on student questions about the data like: What percent of each category is thrown out? How many gallons of food are thrown out? How much "trash" is in the trash? Instead of discussing graphing procedures, the students in Amy's class were able to use the graphs to justify their answers to more meaningful questions.

Technology can also allow for abstract representations that can be used to explore ideas and questions. Developing dynamic spreadsheets is one example of how this can be done in practice (Caulfield et al., 2005). Heather had experience using dynamic spreadsheets as a learner in college and she recognized the power in using them to develop abstract thinking in students. She was able to imagine how these abstract ideas might help students better understand the procedures for calculating fractions, decimals, and percents. Additionally, Heather was able to share this knowledge with Jesse, who shared no prior experiences using dynamic spreadsheets. This knowledge of the power of abstraction with technology took hold in Jesse's thinking as he taught in and reflected during the Technology Partnership Project.

Student engagement is also an important way that students' learning in mathematics is impacted by the integration of technology into instruction. The motivating factors of technology can encourage students not only to engage in a specific lesson, but also to engage in the study of the subject itself. Students who have opportunities for open exploration of mathematical ideas with technology are more motivated to investigate these ideas later in a more formal and systematic way without the technology (Vincent, 2005). Jesse recognized this idea in his own reflection of the Technology Partnership Project. He imagined that the activities during the unit might encourage the students to "go back and learn their algebra" (Jesse, Interview, 2/21/08).

The Technology Specific Pedagogy of a pre-service teacher can be viewed from both a social and a psychological perspective. These perspectives are not disjoint. The way a pre-service teacher reasons pedagogically about teaching mathematics with technology is impacted by his or her overarching conceptions of teaching mathematics with technology and his or her knowledge of students' thinking and learning in mathematics with technology. This study provided concrete examples of what the social and psychological perspectives reveal about the learning of three pre-service teachers across various contexts in their licensure programs. The implications of this work are addressed in the next section.

Norms of Pedagogical Reasoning

In the Learning to Teach with Technology Framework, the social perspective of Technology Specific Pedagogy is described as Norms of Pedagogical Reasoning about Teaching with Technology. Norms of Pedagogical Reasoning govern how classroom teaching practices comes to be known, shared and developed by teachers in their interactions (Little, 2003). Examples of norms of pedagogical reasoning can be seen as units of teacher-to-teacher talk where the teachers exhibit their reasoning about an issue in their practice, when they describe issues in or raise questions about teaching practice, and in their explanations and justifications (Horn, 2005).

Within a group of pre-service teachers, norms about teaching can develop over time and through social interactions (McNeal & Simon, 2000). In this study, the data from the Technology and Pedagogy I course, team planning meetings, and teaching episodes are potential sources for identifying the development of the group norms for pedagogical reasoning. In addition, the researcher acknowledges that there were other social settings in which this development occurred, including: mathematics content coursework, other licensure coursework, and other social interactions outside of the study. While these other settings were beyond the scope of this setting, the available data from the study provide insight into what patterns, if any, were normative within the group. Two repeating ideas related to pedagogical reasoning, *Playing to Learn* and *Lesson Design*, were shared by all three case participants. These repeating ideas were potentially normative as they were seen across the data set.

In the Technology and Pedagogy I course, *Playing to Learn* was a teaching strategy utilized by the course instructor on Day 1 and Day 4. The pre-service teachers experienced this strategy as they learned to use the motion sensors and

Geometer's Sketchpad. During one planning meeting, Jesse and Linda spoke about how to structure a graphing lesson using *Playing to Learn* (Jesse, Plan, 1/29/08). Later, in another planning meeting, Jesse and Heather discussed how *Playing to Learn* would help the children in the future as they continued to use Excel (Jesse, Plan, 2/5/08). Furthermore, all three participants had the opportunity to observe their peers teaching with the pedagogical strategy of *Playing to Learn* during the Technology Partnership Project.

Lesson Design was also an idea that was introduced to the entire cohort during the Technology and Pedagogy I course. Mr. Compton structured the motion sensor labs, the Geometer's Sketchpad activity, and the iPhoto investigation so that the pre-service teachers could experience a variety of lesson structures. Mr. Compton also asked the pre-service teachers to respond on the discussion board to prompts that asked for an analysis of different *Lesson Design* strategies. During the Technology Partnership Project, both pre-service teacher teams used worksheets that resembled the *Lesson Design* that was demonstrated by Mr. Compton. All of the case participants had the opportunity to design, deliver, and observe activities that put their ideas about *Lesson Design* into practice during the Technology Partnership Project.

The research questions that guided this study aimed to identify patterns of participation displayed by participants across the various research contexts. The identified patterns provided insight into pedagogical reasoning that was potentially normative within the group. Future research might investigate how these patterns are displayed by other participants, and how the patterns develop in contexts outside of the study. Collectively, this additional data would contribute to the understanding of what patterns could be classified as norms. However, given the small sample size, and the limited availability of research contexts in this study, claims about normative patterns are not made at this time.

Implications

The results of this study have implications for future educational research as well as implications for those who are in the practice of preparing teachers to teach with technology. This section begins with the ways that this study contributes to the body of research on teaching with technology. It concludes with how the results of the study might help to inform the pedagogical decisions of those charged with preparing teachers.

In the past, much of the research on the role of technology integration in mathematics classes has been done from a psychological perspective of learning (Rivera, 2005). A focus on the psychological perspective is also found in the work that has investigated the development of TPCK (Niess, 2005; Suharwoto & Lee, 2005). This study is a departure from previous studies of TPCK because the results provide insight into how learning to teach with technology can be viewed through a social perspective as well. Technology Specific Pedagogy takes TPCK and fits it into a structure that includes attention paid to the social factors that influence learning. This holistic approach provides additional insight into how pre-service teachers learn to teach with technology by extending the theory beyond the knowledge held by the individual teacher.

The ability to teach mathematics with technology means more than just mastery of skills, it requires an understanding of how the technology tools, mathematical content, and teaching practices interact. Learning by its nature is situated and pre-service teachers need opportunities to solve problems related to teaching with technology that are ill-structured and situated in a real context (Koehler & Mishra, 2005). This study describes one possible way for providing these opportunities during a licensure program. The results demonstrate explicitly how the learning of the pre-service teachers was situated within various contexts.

The results of this study also provide an important resource for the research community as it comes to a better understanding of TPCK. The concept of TPCK has only recently been formalized and more work is needed to understand how it can be developed in pre-service teachers. This study provides a body of repeating ideas that can help to more clearly define the individual components of TPCK. The researcher acknowledges that this study does not present an exhaustive list of repeating ideas that illustrate a pre-service teacher's overarching conception of teaching with technology. However, this study shows how pre-service teachers struggle with *Doing the Technology* versus *Using the Technology*. This study also describes how pre-service teachers view *Technology as a Simplifier/Extension* versus *Technology as an Enhancer/Differentiator*. With these factors identified, researchers can begin to discuss how to develop and assess these ideas with other pre-service teacher populations.

In addition to contributing to a theoretical understanding of pre-service teachers' learning, this study also had implications for those working to prepare teachers for initial licensure. The results of this study demonstrate that pre-service teachers need multiple opportunities and contexts in which to learn to teach with technology and that just knowing the technology is insufficient for teaching mathematics. The development of norms of pedagogical reasoning takes time. For the pre-service teachers in this study, the patterns of participation describe a development of their reasoning about teaching with technology. This development was influenced by their past experiences and formal ideas began to surface during their coursework. However, all of the pre-service teachers changed in their reasoning during the planning, teaching, and reflecting phases of the Technology Partnership Project. The group planning aspect of the Technology Partnership Project required that the pre-service teachers advocate and defend their ideas. It also forced some pre-service teachers to try ideas that conflicted with their own prior understandings. In the end, the time to actually test these ideas during the teaching of the units gave the pre-service teachers concrete examples of their pedagogical reasoning at work. Each of these learning contexts influenced the pre-service teachers' understandings in some way. This study offers evidence of the need for long-term development of Technology Specific Pedagogy that takes place in a variety of contexts.

As instructors design learning opportunities for pre-service teachers in licensure programs, they must consider activities that address foundational understandings of Technology Specific Pedagogy. Mr. Compton, the instructor of the Technology and Pedagogy course in this study, designed a number of activities that helped students to think about the ideas of *Playing to Learn*, *Lesson Design*, *Visualizing with Technology*, and *Motivation*. The results of this study, however, provide a list of additional ideas that could be incorporated into the course activities. Jesse was the only pre-service teachers to express repeating ideas about *Equitable Access*, yet it is an important component of the ISTE Standards for Teachers. *Equitable Access* and Heather's ideas about *Student Control* were not addressed during coursework, but these ideas emerged in other contexts. The results of this study can help future instructors of courses like Technology and Pedagogy to identify ideas that should be addressed during coursework.

Limitations of the Study

The purpose of this study was to characterize the development of pre-service teachers' Technology Specific Pedagogy across a variety of learning contexts. To this end, three pre-service teachers were selected for in depth case study analysis. A wide range of patterns of participation and repeating ideas emerged from the data of the three cases. By selecting only a small number of cases, the researcher was able to focus on creating a rich description of the experiences and ideas of these pre-service teachers. However, the nature of the research methods and the reality of certain uncontrollable events did create some limitations for this study.

This study took place during the first two phases of an initial teacher licensure program and looked at a variety of learning contexts. The results of the study indicate that pre-service teachers develop their Technology Specific Pedagogy over a long period of time, and it would be desirable to continue to track this progress as it goes into full time student teaching and entry into the profession. Learning to teach is a career spanning activity and the ever-changing nature of technology makes this issue even more pronounced. This study, however, aimed to understand the learning of pre-service teachers during the phases over which licensure programs have the most "control"—coursework and part-time field experiences. Clearly, the understanding of Technology Specific Pedagogy could be stronger if the learning of Amy, Heather, and Jesse was followed into the future. While this study aimed to inform how pre-service teachers develop during initial licensure, longer term studies could inform how the needs of practicing teachers should be met.

As with any study, the researcher brings certain biases and beliefs that can potentially impact the research results. The researcher's past teaching experiences and personal beliefs about the role of technology in mathematics may have impacted what was "noticed" and how that data were analyzed. In this study, the researcher took careful steps to minimize this limitation. First, data were collected, organized, and compiled for all participants before the cases were selected. Equivalent data were collected for each participant (e.g. every discussion board posting was collected and all participants were interviewed using the same protocol). All planning and teaching activities were recorded either with digital audio or video so that the transcripts captured the participant's exact words. All data were triangulated by examining artifacts from multiple research contexts. If an idea was shared in fewer than three contexts, it was not considered a pattern of participation. During the analysis phase, the data were examined using a structured system for analyzing qualitative data. A number of repeating ideas were identified that did not address the research questions, but did seem to illuminate other parts of the Learning to Teach with Technology Framework. These ideas were recorded and tabled for future study. Finally, in writing the results of the study, the researcher relied on direct quotes from the pre-service teachers writing or speaking to substantiate claims whenever possible.

Certain events beyond the control of the researcher also created limitations for the study. First, the pre-service teacher teams in the Technology Partnership Project both chose to teach their unit using Excel as their primary technology tool. Heather and Jesse's group also did some work with PowerPoint and digital video, but these technologies were not used in the learning of the mathematical content. The conclusions in this study, especially those from research question two, are limited to those that could be drawn from the experiences of teaching with Excel. Different technology affords different types of learning. A study that includes opportunities to teach with other technology like Geometer's Sketchpad, graphing calculators, or data probes may reveal different repeating ideas, perhaps more of an emphasis on *Abstraction with Technology*, for example. The narrow focus on teaching with spreadsheets did allow the researcher to draw comparisons across the groups, however. The two units developed during the Technology Partnership Project had many similarities, providing the researcher with opportunities to understand more deeply the ways that pre-service teachers teach with spreadsheets in particular.

Another event beyond the researcher's control led to an additional limitation of the study. Ms. Thomas' teaching schedule was structured so that she had her planning period and lunch every day immediately after Heather and Jesse's group finished teaching their lesson. Each day, the entire team gathered in the staff room and reflected on the successes of that day's lesson and discussed their plans for the following day. In all, the researcher attended and recorded eight planning meetings that ranged in length from 10 minutes to 45 minutes. These meetings became a rich source of data and gave valuable insight into the pre-service teachers' thinking and planning during the Technology Partnership Project. However, for Amy's group, these planning meetings did not occur and this additional data was not available for the group. Also, Heather and Jesse's group taught 11 lessons, while Amy's group taught six. In the end, the researcher was able to collect significantly more data on Heather and Jesse's group because of the planning meetings and the length of the unit. The discrepancy in the volume of data meant that conclusions drawn from Heather and Jesse's work had more support. It also led to the case selection of Heather and Jesse over Jin and Gary. In the end, the opportunity to attend these meetings and watch more teaching was a benefit to the researcher, but did mean the experiences of certain pre-service teachers became privileged over others.

Recommendations for Future Research

The results of this study provided three in-depth investigations of pre-service teachers learning to teach with technology. Data were collected on two other participants, but as previously explained, their case studies were not described here. The data from these participants has been collected and organized, and the presentation of two additional cases would be possible in the future. However, examining the learning of students in a different licensure program, working in a different school for the Technology Partnership Project, or teaching with different technology might be a more fruitful place to begin additional research. The three cases presented in this study had many differences, but they also had a lot of similarities. Amy, Jesse, and Heather were white students who had been raised and educated in middle class suburban communities. All three were traditional college students who were enrolled in the same licensure program. By investigating the learning of other students in other contexts, additional patterns of participation and repeating ideas could potentially be identified and a better understand of Technology Specific Pedagogy could result.

In Chapter Two: Review of the Literature, the Learning to Teach with Technology Framework was presented as a way to characterize the learning of pre-service teachers from a social and psychological perspective. The Framework addressed three domains of professional expertise: Professional Identity, Technology Specific Pedagogy, and Content Knowledge. This study provided an in-depth investigation of only one of those domains. During the data analysis, some repeating ideas emerged that related to the components of Professional Identity and Content Knowledge. Further investigation of these ideas was beyond the scope of the study, but their emergence hinted at the potential for additional understandings. Specifically, a better understanding is needed about:

- Pre-service teachers' beliefs about their own role, others' role and the general nature of technology
- Classroom pedagogical practices with technology
- Pre-service teachers' knowledge of instructional strategies and representations for teaching with technologies
- Pre-service teachers' knowledge of curriculum and curricular materials

As the individual elements of the Learning to Teach with Technology Framework are better understood, recommendations about how to address individual pre-service teachers' patterns of participation could be developed. For example, the results of this study indicate that pre-service teachers struggle with ideas related *Doing Technology* in mathematics classes versus *Using Technology* to learn mathematics. What are the activities that can help pre-service teachers move away from ideas that are less productive for student learning and move toward ideas that enhance student learning? After the Technology Partnership Project, Amy began to question the purpose and effectiveness of "doing Excel" in mathematics classes. What follow-up activities should Amy participate in that will help her to continue this line of reflective thinking? Jesse was the only pre-service teacher to share ideas related to *Equitable Access*. What are the activities and contexts that would engage Amy and Heather in addressing this important technology standard?

Conclusion

When Lee Shulman first presented the idea of pedagogical content knowledge (PCK), he launched an entire line of educational research that continues today. First, researchers worked to define what PCK meant in a more explicit way (Grossman, 1990; Grossman et al., 1989; Shulman & Grossman, 1988). Next, the research community examined the role of PCK in the preparation of teachers in various subject areas, including mathematics (Ball, 2000; Borko & Putnam, 1996; Ma, 1999). More recently, work has begun on how to effectively assess PCK and its development in pre-service and in-service teachers (Hill, Rowan, & Ball, 2005; Hill, Schilling, & Ball, 2004).

As the story for PCK, so will be the story for TPCK. The research community began investigating the knowledge needed to teach with technology only recently (Keating & Evans, 2001; Pierson, 2001). A formal definition of a framework for TPCK is even newer (Mishra & Koehler, 2006; Niess, 2005). Examination of the role of TPCK in the preparation of teachers of mathematics has now begun in earnest (Hughes, 2004, 2005; Suharwoto & Lee, 2005). It is intended that this study be a contribution to the effort to understand how pre-service teachers come to know how to teach with technology. Perhaps the ideas of Amy, Heather, and Jesse will contribute in some meaningful way to the learning of pre-service teachers in the years to come.

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APPENDICES

APPENDIX A

National Educational Technology Standards for Students: The Next Generation

1. Creativity and Innovation

Students demonstrate creative thinking, construct knowledge, and develop innovative products and processes using technology. Students:

a. apply existing knowledge to generate new ideas, products, or processes.

b. create original works as a means of personal or group expression.

c. use models and simulations to explore complex systems and issues.

d. identify trends and forecast possibilities.

2. Communication and Collaboration

Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others. Students:

a. interact, collaborate, and publish with peers, experts or others employing a variety of digital environments and media.

b. communicate information and ideas effectively to multiple audiences using a variety of media and formats.

c. develop cultural understanding and global awareness by engaging with learners of other cultures.

d. contribute to project teams to produce original works or solve problems.

3. Research and Information Fluency

Students apply digital tools to gather, evaluate, and use information. Students:

a. plan strategies to guide inquiry.

b. locate, organize, analyze, evaluate, synthesize, and ethically use information from a variety of sources and media.

c. evaluate and select information sources and digital tools based on the appropriateness to specific tasks.

d. process data and report results.

4. Critical Thinking, Problem-Solving & Decision-Making

Students use critical thinking skills to plan and conduct research, manage projects, solve problems and make informed decisions using appropriate digital tools and resources. Students:

a. identify and define authentic problems and significant questions for investigation.

b. plan and manage activities to develop a solution or complete a project.

c. collect and analyze data to identify solutions and/or make informed decisions.

d. use multiple processes and diverse perspectives to explore alternative solutions.

5. Digital Citizenship

Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior. Students:

a. advocate and practice safe, legal, and responsible use of information and technology.

b. exhibit a positive attitude toward using technology that supports collaboration, learning, and productivity.

c. demonstrate personal responsibility for lifelong learning.

d. exhibit leadership for digital citizenship.

6. Technology Operations and Concepts

Students demonstrate a sound understanding of technology concepts, systems and operations. Students:

a. understand and use technology systems.

b. select and use applications effectively and productively.

c. troubleshoot systems and applications.

d. transfer current knowledge to learning of new technologies.

APPENDIX B

NETS for Teachers

Educational Technology Standards and Performance Indicators for All Teachers

1 TECHNOLOGY OPERATIONS AND CONCEPTS.
Teachers demonstrate a sound understanding of technology operations and concepts. Teachers:

- demonstrate introductory knowledge, skills, and understanding of concepts related to technology (as described in the ISTE National Education Technology Standards for Students)
- demonstrate continual growth in technology knowledge and skills to stay abreast of current and emerging technologies.

2 PLANNING AND DESIGNING LEARNING ENVIRONMENTS AND EXPERIENCES.
Teachers plan and design effective learning environments and experiences supported by technology. Teachers:

- design developmentally appropriate learning opportunities that apply technology-enhanced instructional strategies to support the diverse needs of learners.
- apply current research on teaching and learning with technology when planning learning environments and experiences.
- identify and locate technology resources and evaluate them for accuracy and suitability.
- plan for the management of technology resources within the context of learning activities.
- plan strategies to manage student learning in a technology-enhanced environment.

3 TEACHING, LEARNING, AND THE CURRICULUM.
Teachers implement curriculum plans that include methods and strategies for applying technology to maximize student learning. Teachers:

- facilitate technology-enhanced experiences that address content standards and student technology standards.
- use technology to support learner-centered strategies that address the diverse needs of students.
- apply technology to develop students' higher order skills and creativity.
- manage student learning activities in a technology-enhanced environment.
-

4 ASSESSMENT AND EVALUATION.
Teachers apply technology to facilitate a variety of effective assessment and evaluation strategies. Teachers:

- apply technology in assessing student learning of subject matter using a variety of assessment techniques.

- use technology resources to collect and analyze data, interpret results, and communicate findings to improve instructional practice and maximize student learning.
- apply multiple methods of evaluation to determine students' appropriate use of technology resources for learning, communication, and productivity.

5 PRODUCTIVITY AND PROFESSIONAL PRACTICE.
Teachers use technology to enhance their productivity and professional practice. Teachers:

- use technology resources to engage in ongoing professional development and lifelong learning.
- continually evaluate and reflect on professional practice to make informed decisions regarding the use of technology in support of student learning.
- apply technology to increase productivity.
- use technology to communicate and collaborate with peers, parents, and the larger community in order to nurture student learning.

6 SOCIAL, ETHICAL, LEGAL, AND HUMAN ISSUES.
Teachers understand the social, ethical, legal, and human issues surrounding the use of technology in PK-12 schools and apply those principles in practice. Teachers:

- model and teach legal and ethical practice related to technology use.
- apply technology resources to enable and empower learners with diverse backgrounds, characteristics, and abilities.
- identify and use technology resources that affirm diversity
- promote safe and healthy use of technology resources.
- facilitate equitable access to technology resources for all students.

APPENDIX C

Professional Preparation Performance Profile

Prior to the culminating student teaching or internship experience, prospective teachers:

1. identify the benefits of technology to maximize student learning and facilitate higher order thinking skills. (I, III)

2. differentiate between appropriate and inappropriate uses of technology for teaching and learning while using electronic resources to design and implement learning activities. (II, III, V, VI)

3. identify technology resources available in schools and analyze how accessibility to those resources affects planning for instruction. (I, II)

4. identify, select, and use hardware and software technology resources specially designed for use by PK-12 students to meet specific teaching and learning objectives. (I, II)

5. plan for the management of electronic instructional resources within a lesson design by identifying potential problems and planning for solutions. (II)

6. identify specific technology applications and resources that maximize student learning, address learner needs, and affirm diversity. (III, VI)

7. design and teach technology-enriched learning activities that connect content standards with student technology standards and meet the diverse needs of students. (II, III, IV, VI)

8. design and peer teach a lesson that meets content area standards and reflects the current best practices in teaching and learning with technology. (II, III)

9. plan and teach student-centered learning activities and lessons in which students apply technology tools and resources. (II, III)

10. research and evaluate the accuracy, relevance, appropriateness, comprehensiveness, and bias of electronic information resources to be used by students. (II, IV, V, VI)

11. discuss technology-based assessment and evaluation strategies. (IV)

12. examine multiple strategies for evaluating technology-based student products and the processes used to create those products. (IV)

13. examine technology tools used to collect, analyze, interpret, represent, and communicate student performance data.(I, IV)

14. integrate technology-based assessment strategies and tools into plans for evaluating specific learning activities. (IV)

15. develop a portfolio of technology-based products from coursework, including the related assessment tools. (IV, V)

16. identify and engage in technology-based opportunities for professional education and lifelong learning, including the use of distance education. (V)

17. apply online and other technology resources to support problem solving and related decision making for maximizing student learning. (III, V)

18. participate in online professional collaborations with peers and experts. (III, V)

19. use technology productivity tools to complete required professional tasks. (V)

20. identify technology-related legal and ethical issues, including copyright, privacy, and security of technology systems, data, and information. (VI)

21. examine acceptable use policies for the use of technology in schools, including strategies for addressing threats to security of technology systems, data, and information. (VI)

22. identify issues related to equitable access to technology in school, community, and home environments. (VI)

23. identify safety and health issues related to technology use in schools. (VI)

24. identify and use assistive technologies to meet the special physical needs of students. (VI)

APPENDIX D

ISTE General Preparation Profile for Prospective Teachers Survey

Prospective Teachers Survey:
NAME:________________________________
Date: __________

Instructions: Select one level of agreement for each statement to indicate how you at this time. Place an "x" in the appropriate cell/box.

SD = Strongly Disagree D = Disagree U = Undecided A = Agree SA = Strongly Agree

Statement	SD	D	U	A	SA
1. I have a strong understanding of the nature and operation of technology systems.					
2. I am proficient in the use of common input and output devices; I can solve routine hardware and software problems; I can make informed choices about technology systems, resources, and services.					
3. I can use technology tools and information resources to increase productivity, promote creativity, and facilitate academic learning.					
4. I can use content-specific tools (e.g., software, simulation, environmental probes, graphing calculators, exploratory environments, Web tools) to support learning and research.					
5. I can use technology resources to facilitate higher order and complex thinking skills, including problem solving, critical thinking, informed decision-making, knowledge construction, and creativity.					
6. I can collaborate in constructing technology-enhanced models, preparing publications, and producing other creative works using productivity tools.					
7. I can use technology to locate, evaluate, and collect information from a variety of sources.					
8. I can use technology tools to process data and report results.					
9. I can use technology in the development of strategies for solving problems in the real world.					
10. I have observed and experienced the use of technology in my major field of study.					
11. I can use technology tools and resources for managing and communicating information (e.g.,					

finances, schedules, address, purchases, correspondence).					
12. I can evaluate and select new information resources and technological innovations based on their appropriateness to specific tasks.					
13. I can use a variety of media and formats, including telecommunications, to collaborate, publish, and interact with peers, experts, and other audiences.					
14. I understand the legal, ethical, cultural, and societal issues related to technology.					
15. I have a positive attitude toward technology uses that support lifelong learning, collaboration, personal pursuits, and productivity.					
16. I can discuss diversity issues related to electronic media.					
17. I can discuss the health and safety issues related to technology use.					

APPENDIX E

Individual Interview Protocol

Pre-service teacher name:	Date:	Location:
File:	Interviewer:	Start time/end time:

1. Can you tell me about your mathematics background?
2. Can you tell me about your technology background?
3. What were the objectives of the lesson sequence? How well did this lesson meet the learning objectives that you planned for this sequence?
4. How did your group decide what you were going to teach and how you were going to teach it?
5. Did anything unexpected happen during the lesson?
6. In what ways did the technology improve your ability for students to learn the mathematics content?
7. If you were to teach these objectives again without the use of the technology, how would the K-12 students' learning be different?
8. What do you think the role of technology is in teaching mathematics to your students?
9. Can you think of an example of a math concept that students would learn more effectively or thoroughly if it were taught using technology?
10. Can you think of an example of a math concept that students would learn more effectively or thoroughly if it were taught using technology?
11. As a result of this project, do you have any other learning goals for your self in the future?
12. Is there anything that I haven't asked you that you would like to add?

APPENDIX F

Permission to use ISTE Instruments

From: Diane Durrett [ddurrett@iste.org]
Sent: Monday, July 30, 2007 3:20 PM
To: harrinra@onid.orst.edu
Subject: FW: Technology Competence Survey and General Preparation Profile for Prospective Teachers Survey

Dear Ms. Harrington,
Thank you for your interest in using ISTE materials.

You have ISTE's permission to use the National Educational Technology Standards for Teachers content that you describe below in the development of your research proposal. This permission is granted for no fee as long as there is no monetary gain from the use of this material and for educational purposes only. This authorization is for this one-time use only and is nontransferable. Please use the following credit statement:

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Unfortunately, we do not have the material available in a digital format that could be easily sent to you.

Best regards,

Diane Durrett
ISTE, web: www.iste.org
P: (541) 434-8925
F: (541) 302-3780
E: ddurrett@iste.org

APPENDIX G

Informed Consent Document

Project Title:	**Pre-service Teachers' Development of Technology Specific Pedagogy**
Principal Investigator:	**Dr. Maggie Niess, Science and Mathematics Education**
Co-Investigator(s):	**Rachel Harrington, Science and Mathematics Education**

WHAT IS THE PURPOSE OF THIS STUDY?

You are being invited to take part in a research study designed to understand the ways that pre-service teachers learn to teach mathematics with technology. *Where* something is learned impacts how and what is learned, so this study will investigate how pre-service teachers learn to teach with technology during the Technology Partnership Research Project. This study will result in a student thesis project, journal articles, and will be shared at conferences for educational researchers. We are studying this because learning to teach with technology is challenging and teacher preparation programs need more information on how to help pre-service teachers accomplish this task.

WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are an in-service or pre-service teacher participating in the Technology Partnership Research Project.

WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?

To document pre-service teachers' learning to teach with technology, we will ask participants to complete two video-taped and audio-taped interviews. The first interview will be a group interview with your teaching team. The second interview will be an individual interview. In addition, the lesson that you team-teach in the field will be videotaped. If you agree to take part in this study, your involvement will last for the duration of the Technology Partnership Research Project (for Winter term, 2008).

WHAT ARE THE RISKS OF THIS STUDY?

There are no foreseeable risks to participation in the study. There may be some normal, mild anxiety because of video- and audio-recording devices. We will situate the recording devices in unobtrusive locations in the room and use small recording devices to minimize these risks.

Your participation in this research will not impact your role in the Technology Partnership Research Project.

WHAT ARE THE BENEFITS OF THIS STUDY?

There are no direct benefits to participants as a result of this research.

We do not know if you will benefit from being in this study. However, we hope that, in the future, other people might benefit from this study because of the knowledge gained through this process might enable others to better design professional development experiences for leaders.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for participating in this study.

WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, you will be given a number or pseudonym, if your comments are quoted in text or presentations. All identifying demographic information will be stated in generalities or removed from video, such as a "pre-service teacher from the West Coast of the United States" or blurring of identifying information. We will use your number or pseudonym to identify your comments on transcripts of audio or video tapes. All transcripts, tapes, and the key to your identify number or pseudonym will be stored in a locked office or on a password-protected computer. If the results of this project are published in an article or the data set shared with others, your identity will not be made public. Only those participants consenting to participate in this project may have their image used in presentations.

To collect data for this study we will video- and audio-tape the interviews and the lesson sequence (3-5 lessons) that you team-teach. During the Technology Partnership Research Project, in-service teacher and pre-service teacher teams will meet between one and three times to plan lessons. Each meeting is estimated to take 20-45 minutes. We will also audio-tape any planning sessions that occur between the teams. It is anticipated that We will use video and audio-tape because it allows us to document the events as they unfold with more accuracy and to quote exactly what is said, rather than trying to capture everything in writing. Video-tapes also provide a vivid picture of what takes place in the classroom, more than written transcripts of events. If video-tapes are to be used in research presentation all references to identifying information will be dubbed, pseudonyms used, and those not participating in the study will be blurred on the tape. If the results of this project are published, your identity will not be made public.

It is possible that the data collected for this project may be used for similar studies pre-service teacher learning. Because we cannot predict what studies may be a part of future work, we are asking that you give us permission to use these data, removing all identifying information, without being contacted about each future study. Participants may change their status in the project at any time by contacting the Principal Investigator, Dr. Maggie Niess, 541-737-1818, niessm@onid.orst.edu.

DO I HAVE A CHOICE TO BE IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop your participation in this study at any time during the Technology Partnership Research Project and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

WHAT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Dr. Maggie Niess at niessm@onid.orst.edu or 541-737-1818.

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed):
____

____
(Signature of Participant) (Date)

Please check the appropriate boxes:

☐ **I agree** to participate in the project: Pre-service teachers' Development of Technology Specific Pedagogy

☐ **I decline** to participate in the project: Pre-service teachers' Development of Technology Specific Pedagogy. You may also leave the form blank to indicate that you decline to participate in the project.